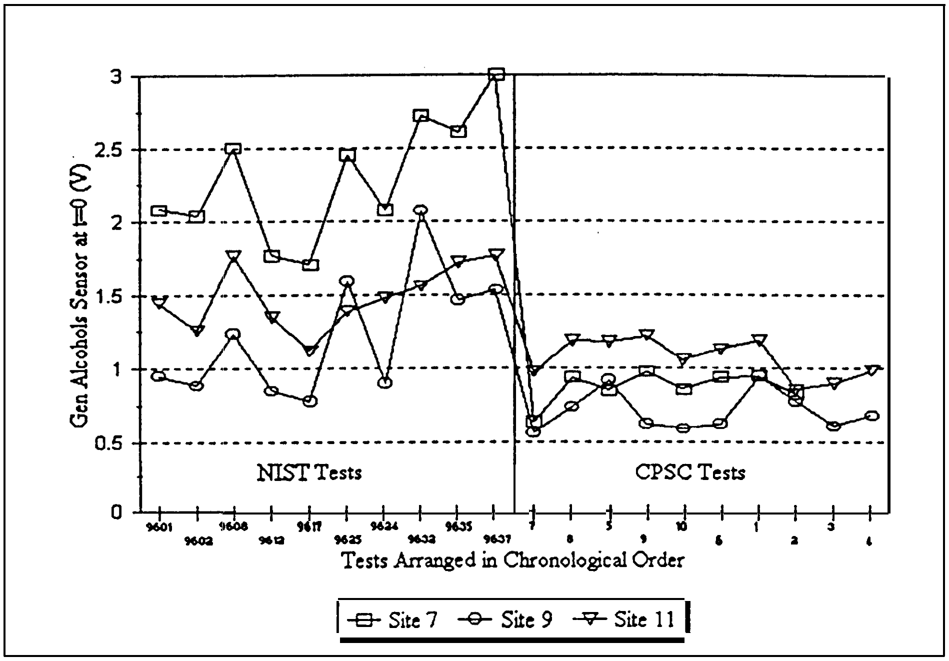

Figure 10.1.3.2B: General alcohol sensor initial voltage offsets versus chronological occurrence of tests

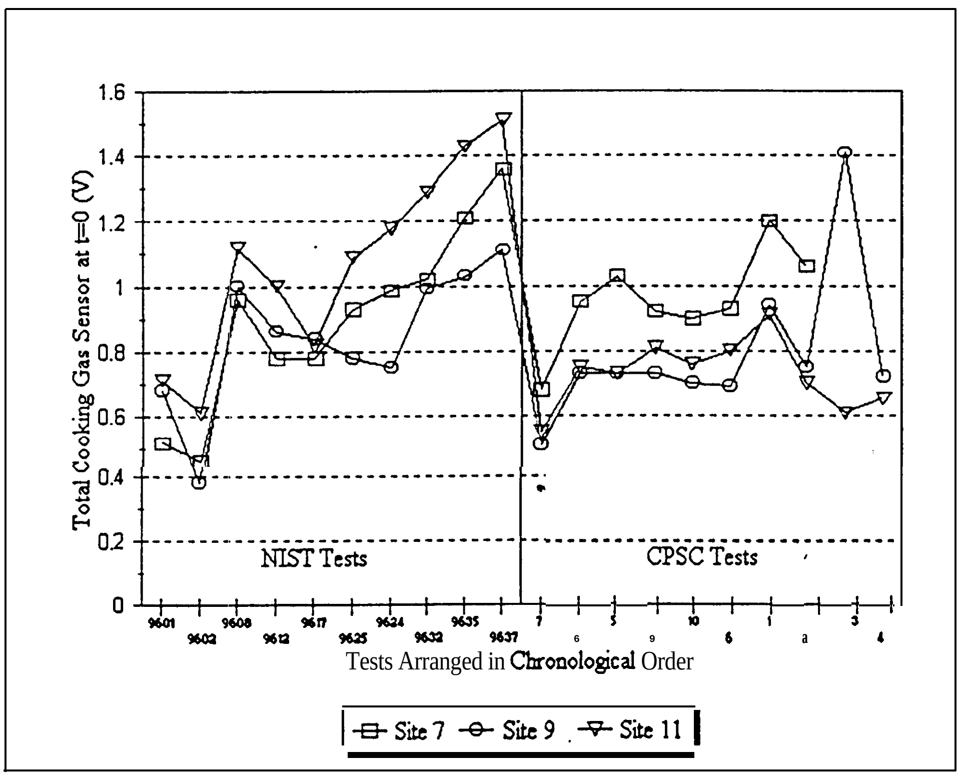

Figure 10.1.3.2C: Total cooking sensor initial voltage offsets versus chronological occurrence of tests

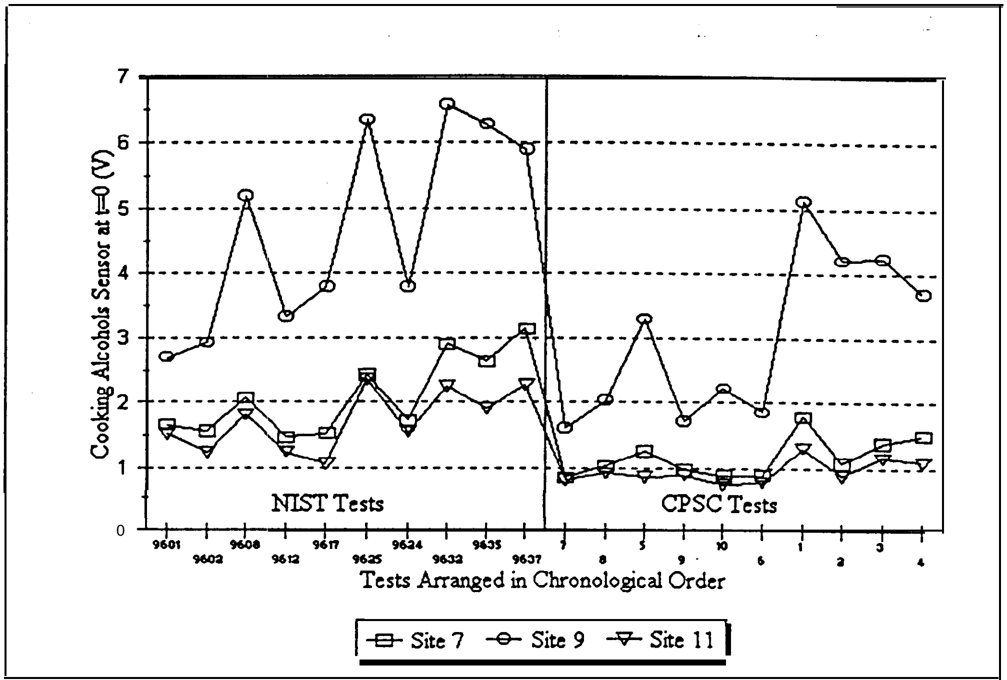

Figure 10.1.3.2D: Cooking alcohol sensor initial voltage offsets versus chronological occurrence of tests

The following four Tables (Tables 10.1.3.2A through 10.1.3.2D) compare the instantaneous voltage readings of the various gas sensors at the time of ignition and at 120 seconds before ignition with the initial voltages subtracted. These tables indicate that both the hydrocarbon and cooking alcohol sensors performed best at ignition, with the least degree of variability. The sensor output voltage readings at 0 and 120 seconds before ignition minus initial voltage readings from the CPSC tests tended to be somewhat lower than the NIST readings. Although they are generally comparable, this may be due to the aging and degradation of the sensors as previously mentioned. Voltage readings at 120 seconds before ignition minus the initial voltage readings were substantially lower than the readings at ignition for all tests except the chicken tests. Figure 10.1.3.2E, which is a plot of the general alcohol sensor at site 9 for the bacon cooking scenario for both laboratories illustrates the differences seen throughout the tests. The order in which; the four tests took place is the same as the order in which the test runs are listed in the legend. During each subsequent run, the sensor response seems to be diminished. Since the ambient temperatures for each of these four test runs were within 3°C (54°F) of each other, the effect may be related to sensor contamination.

Table 10.1.3.2A: Numerical Comparison of Site 9 General Hydrocarbon Sensor Data

	Oil		Bacon		Soybean Oil & Water (Electric Stove)		Chicken	
Ignition Voltage - Initial Voltage	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev to Mean	Sensor Output (V)	No. of Std Dev from Mean
NIST 1	7.52	1.37	9.97	-1.18	6.08	1.12	12.96	1.47
NIST 2	4.30	-0.93	11.52	0.92	3.05	-0.91	9.52	-0.75
CPSC 1	4.92	-0.49	11.37	0.72	3.25	-0.78	10.24	-0.28
CPSC 2	5.65	0.04	10.49	-0.47	5.25	0.56	9.99	-0.45
Mean	5.60		10.84		4.41		10.68	
Standard Deviation	1.40		0.74		1.49		1.55	
Coefficient of Variation (Std Dev as % Mean)	24.93%		6.79%		33.88%		14.52%	
120 Seconds Before Ignition Voltage - Initial Voltage	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean
NIST 1	1.67	-0.30	7.66	0.89	2.25	-0.25	11.59	1.03
NIST 2	1.12	-1.29	7.38	0.78	2.05	-0.44	10.49	-0.11
CPSC 1	2.24	0.71	3.91	-0.51	1.67	-0.78	9.32	-1.33
CPSC 2	2.31	0.84	2.18	-1.16	4.14	1.46	10.99	0.41
Mean of Four Values	1.84		5.28		2.53		10.60	
Standard Deviation	0.56		2.68		1.10		0.96	
Coefficient of Variation (Std Dev as % Mean)	30.31%		50.75%		43.58%		9.09%	

Table 10.1.3.2B: Numerical Comparison of Site 9 General. Alcohols Sensor Data

	Oil		Bacon		Soybean Oil & Water (Electric Stove)		Chicken	
Ignition Voltage - Initial Voltage	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean
NIST 1	11.81	1.49	12.00	0.87	8.84	1.31	13.28	1.01
NIST 2	5.75	-0.43	11.67	0.70	4.76	-0.20	12.84	0.71
CPSC 1	5.13	-0.63	9.75	-0.27	2.30	-1.11	10.54	-0.86
CPSC 2	5.74	-0.43	7.71	-1.30	5.33	0.01	10.54	-0.86
Mean of Four Values	7.11		10.28		5.31		11.80.	
Standard Deviation	3.15		1.98		2.70		1.47	
Coefficient of Variation (Std Dev as % Mean)	44.30%		19.27%		50.82%		12.42%	
120 Seconds Before Ignition Voltage - Initial Voltage	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean
NIST 1	4.24	1.44	6.29	1.07	3.27	0.50	1138	0.81
NIST 2	1.57	-0.86	5.23	0.61	2.36	0.18	11.56	0.91
CPSC 1	2.10	-0.41	2.29	-0.67	0.85	-1.32	8.37	-0.95
CPSC 2	2.35	-0.19	1.50	-1.01	3.92	0.99	8.68	-0.77
Mean of Four Values	2.57		3.83		2.60		10.00	
Standard Deviation	1.16		2.30		1.33		1.71	
Coefficient of Variation (Std Dev as % Mean)	45.34%		59.95%		51.18%		17.07%	

Table 10.1.3.2C: Numerical Comparison of Site 9 Total Cooking Gas Sensor Data

	Oil		Bacon		Soybean Oil & Water (Electric Stove)		Chicken	
Ignition Voltage - Initial Voltage	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean
NIST 1			8.87	0.35	5.94	1.29	12.22	1.47
NIST 2	3.18	-0.44	9.74	0.96	2.60	0.58	9.17	-0.25
CPSC 1	3.05	-069	8.48	0.08	1.89	-0.97	8.70	-0.52
CPSC 2	4.01	1.15	6.40	-1.39	4.07	0.25	8.38	-0.70
Mean of Four Values	3.41		8.37		3.63		9.62	
Standard Deviation	0.52		1.42		1.79		1.77	
Coefficient of Variation (Std Dev as % Mean)	15.26%		16.92%		49.39%		18.35%	
120 Seconds Before Ignition Voltage - Initial Voltage	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean
NIST 1			6.38	1.09	2.59	1.29	10.16	1.47
NIST 2	1.26	-1.00	5.15	0.59	1.81	-0.58	8.10	-0.25
CPSC 1	1.44	0.00	2.08	-0.65	1.19	-0.97	7.75	-0.54
CPSC 2	1.62	1.00	1.16	-1.02	2.84	0.25	7.57	0.69
Mean of Four Values	1.44		3.69		2.11		8.40	
Standard Deviation	0.18		2.47		0.75		1.20	
Coefficient of Variation (Std Dev as % Mean)	12.50%		67.00%		35.72%		14.26%	

Table IO. 1.3.2D: Numerical Comparison of Site 9 Cooking Alcohols Gas Sensor Data

	Oil		Bacon		Soybean Oil & Water (Electric Stove)		Chicken	
Ignition Voltage - Initial Voltage	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean
NIST 1	10.58	1.35	10.89	0.84	9.30	1.09	9.49	-0.23
NIST 2	6.55	-1.07	10.06	-0.07	5.20	-0.35	8.16	-1.25
CPSC 1	8.25	-0.05	10.68	0.61	2.73	-1.21	10.28	0.38
CPSC 2	7.93	-0.24	8.85	-1.38	7.53	0.47	11.23	1.11
Mean of Four Values	8.33		10.12		6.19		9.79	
Standard Deviation	1.67		0.92		2.85		1.30	
Coefficient of Variation (Std Dev as % Mean)	20.09%		9.06%		46.09%		13.27	
120 Seconds Before Ignition Voltage - Initial Voltage	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean	Sensor Output (V)	No. of Std Dev from Mean
NIST 1	5.46	1.24	7.30	1.25	5.21	0.94	8.74	-0.32
NIST 2	2.89	-1.21	5.17	0.33	3.00	-0.42	7.82	-1.15
CPSC 1	4.18	0.02	3.04	-0.60	1.71	-1.22	9.37	0.24
CPSC 2	4.12	-0.04	2.17	-0.98	4.79	0.69	10.45	1.22
Mean of Four Values	4.16		4.42		3.68		9.10	
Standard Deviation	1.05		2.30		1.62		1.11	
Coefficient of Variation (Std Dev as % Mean)	25.22%		51.96%		44.17%		12.15%	

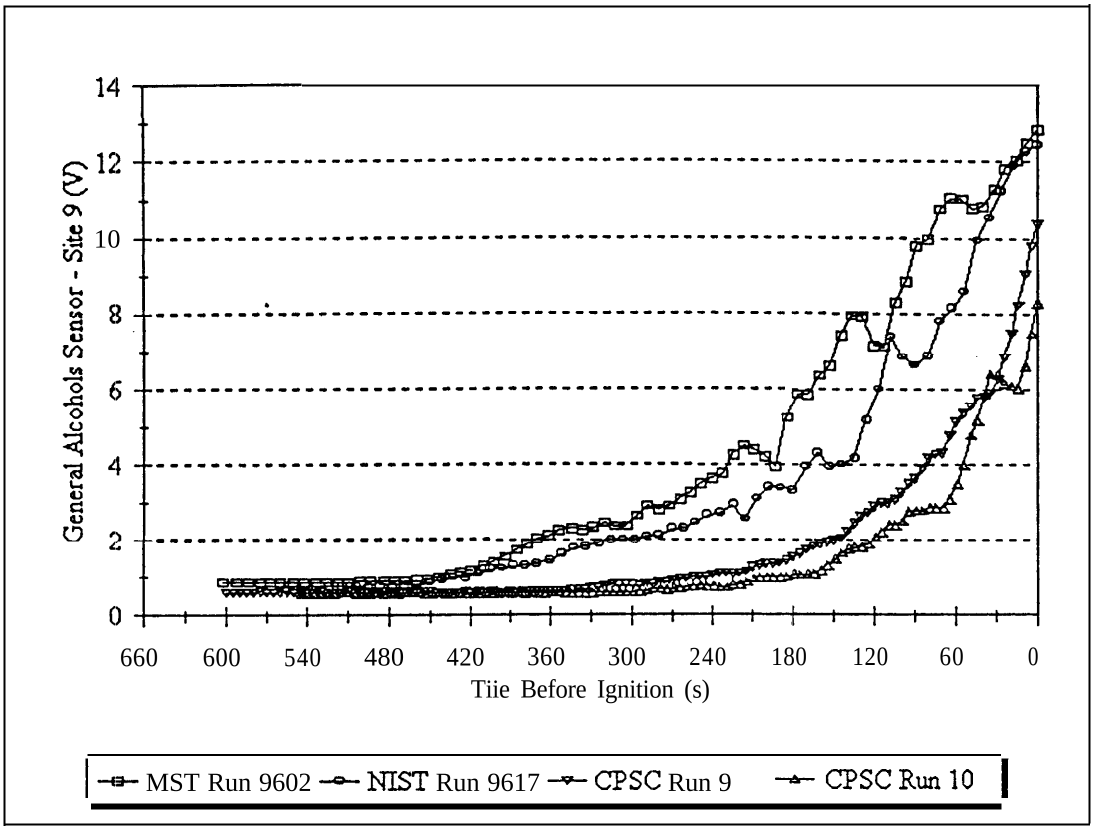

Figure 10.1.3.2E: Site 9 general alcohol sensor outputs for the bacon test scenario

Another means of evaluating the gas sensor data from the two laboratories was to compare the general slope of the output voltage in the region just before ignition. A linear regression was performed on the last 180 seconds before ignition of each of the Site 9 sensor voltages. The choice of 180 seconds was arbitrary, but this was done so that sufficient number of data points were used for linear regression (32 points). The slope of this line was then calculated and tabulated in Table 10.1.3.2E. For the short ignition time scenarios, the slopes compare well (with the exception of the general alcohol sensor for the oil scenario only). The longer duration scenarios produced inconsistent results. Both the CPSC and NIST data for a given scenario show greater repeatability. Despite the numerical differences that have been noted, the data overall have the semblance of comparability between the two test facilities.

10.1.4 Summary

The detection devices that exhibited significant pre-fire signals were the same for CPSC and NIST tests (e.g., pan bottom thermocouples, cooking gas sensors at certain locations, etc.). Detection devices signals for CPSC and NIST tests showed reproducibility especially with regard to temperatures. The detection devices that were eliminated from future analysis because of a lack of significant response (e.g., range top surface mounted thermocouples, carbon monoxide sensors, etc.) also were the same in both NIST and CPSC tests.

Table 10.1.3.2E: Slope of linear regression of last 180 seconds (before ignition) for Site 9 gas sensors

Scenario	Test	General Hydrocarbon (mV/sec)	General Alcohols (mV/sec)	Total Cooking Gases (mV/sec)	Cooking Alcohols (mV/sec)
Bacon	NIST 1	25.2	40.2	27.0	32.6
	NIST 2	60.9	53.0	45.1	38.4
	CPSC 1	60.0	42.0	42.6	54.3
	CPSC 2	54.8	36.5	32.9	47.6
500 ml Soybean Oil	NIST 1	19.8	38.0	-	32.4
	NIST 2	26.8	35.3	17.4	30.2
	CPSC 1	18.8	20.8	12.0	31.5
	CPSC 2	18.6	20.2	13.7	28.2
Soybean Oil and Water	NIST 1	26.0	37.5	25.3	29.5
	NIST 2	15.7	21.8	11.8	17.2
	CPSC 1	9.9	9.3	4.6	6.3
	CPSC 2	6.7	5.8	2.4	2.8
Chicken	NIST 1	3.5	14.7	6.8	6.3
	NIST 2	-29.7	5.0	-9.7	2.0
	CPSC 1	7.7	18.4	9.3	7.5
	CPSC 2	-7.3	15.1	-5.1	8.1

10.1.5 Introduction to Sections 10.2 Through 10.4

Sections 10.2 through 10.4 deal with three aspects of the CPSC test program that need to be presented so that the remainder of the test program may be placed in proper perspective. These sections deal with the 30 ml of soybean oil tests, thermal inertia, and ignition temperatures, respectively.

The 30 ml of oil tests (section 10.2) were originally called for in the test plan, but were -found to produce unreliable pan content temperatures and in subsequent tests for thermal inertia 100 ml of oil was used. Thermal inertia tests (section 10.3) were then performed using 100 ml as the low oil volume to establish pan content and pan bottom temperatures at which ignition is unlikely. After the burner is turned off, the residual heat in the electric burner coils can raise the content temperature sufficiently to cause ignition; it is not a problem with gas ranges. The section on ignition temperatures (section 10.4) takes thermal inertia into account and establishes a pan bottom temperature at which the burner can be turned off and ignition is unlikely (340°C [644°F]). This temperature provides a reference point at which gas sensors and smoke detectors need to be assessed to determine their effectiveness in preventing pre-fire situations. Throughout the remainder of this study, pan bottom temperatures are limited to around 340°C (644°F).

10.2 TEST SCENARIOS WITH 30 ML OF SOYBEAN OIL

For this series of tests, the CPSC test plan specified the use of 30 ml of soybean oil as the pan contents. Initial data indicated variation in pan content temperatures. Stainless steel clad with and without stainless steel cladding, heavy aluminum pans, and transparent, smoke colored ceramic pans were subjected to either high or medium-high heat. All tests were performed on the front right heating element of an open coil element electric range. Table 10.2A presents the test descriptions and results for the high heat settings. For this series of tests, the pan bottom and content temperatures, general hydrocarbon and cooking alcohol sensor signals were measured.

Table 10.2A: Data for test scenarios using 30 ml of soybean oil heated on the right front burner on 10" (254 mm) diameter pans of various materials.

Test Run Number	Time between ignition Voltage and 30% of ignition voltage (sec)						Ignition Temperature (°C)	
	HC Site 7	Alc Site 7	HC Site 9	Alc Site 9	HC Site 11	Alc Site 11	Pan Bottom	Pan Content
10" (254 mm) diameter transparent ceramic pan								
19	20	N/R	30	N/R	90	60	288.68	415.82
20	45	50	70	65	105	70	316.21	397.50
10" (254 mm) diameter heavy aluminum pan								
27	140	100	100	130	90	75	442.16	345.82
28	160	140	115	145	115	100	424.18	413.78
30	130	110	110	120	105	85	436.41	439.86
10" (254 mm) stainless steel pan								
39	190	175	190	175	205	170	452.77	426.87
40	125	110	100	115	80	75	486.74	484.93

HC=General Hydrocarbon Sensor; Alc=Cooking Alcohol Sensor
All tests in this table were run at the high heat setting.
N/R: No response

Comparisons were made only on tests where ignition occurred on both the initial and duplicate tests of the same scenario (tests 29, 37, and 38 are not included in Table 10.2A because ignition did not occur on replicate tests for the same scenario). Three scenarios were compared: tests 19 and 20 with a ceramic pan, tests 27, 28, and 30 with a heavy aluminum pan, and tests 39 and 40 with a stainless steel pan.

For all 30 ml tests, the general hydrocarbon and cooking alcohol sensors exhibited up to a 3V variation in baseline voltages. A 3V variation in sensor voltages at ignition was also observed. Because of these inconsistences, the tests were compared using the time between the sensor response at ignition and 30% of the ignition response.

Sensor responses with the ceramic pan showed the least variation at site 11. There was as much as two-fold variation of response at sites 7 and 9. This may relate to uneven heating of the pan. Sensor responses with the aluminum pan showed the least variation for all sites. The degree of variation in sensor response with stainless steel panswas similar to those observed with ceramic pans except that site 11 showed a variation of greater than two-fold. Responses for sensors with stainless steel pans were clearly higher than for ceramic pans and more closely resembled those of aluminum pans.

The pan bottom temperatures at ignition were fairly consistent for each pan type (Table 10.2A). Ceramic pans had the lowest pan bottom temperatures and stainless steel the highest. The

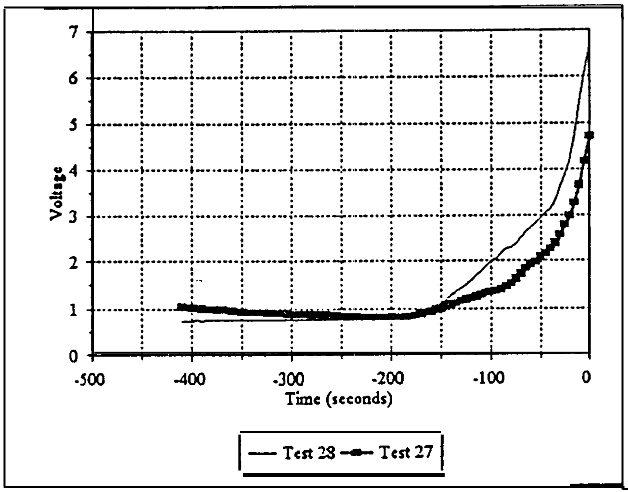

Figure 10.2A: Tests 27 and 28; test scenario -- 30 ml of soybean oil heated on the high setting using a 10" (254 mm) diameter heavy aluminum pan. Site 7 general hydrocarbon sensor's output voltage plotted against time.

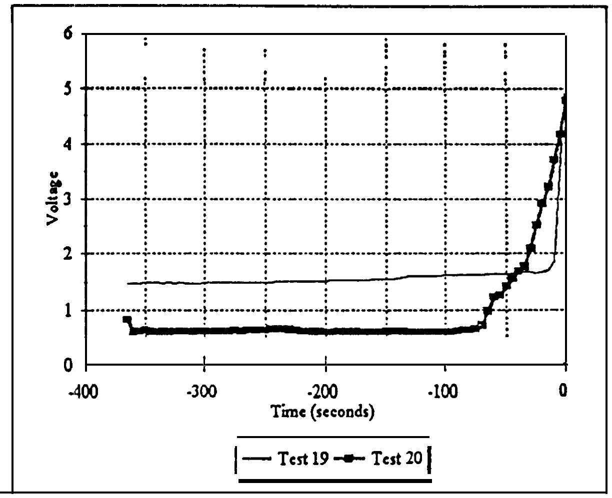

Figure 10.2B: Tests 19 and 20. Test scenario -- 30 ml of soybean oil heated on the high setting using a 10" (254 mm) diameter ceramic pan. Site 7 genera1 hydrocarbon sensor output plotted against time.

aluminum and stainless steel pan bottom temperatures were fairly close. The low ceramic temperature is probably an artifact related to the poor conductivity of the ceramic pan (see section 10.52). The pan content temperatures were not consistent especially in the case of the aluminum pans '(note tests 27 versus tests 28 and 29 as well as tests 39 and 48). As discussed below in section 10.4, the 30 ml of oil tests produced both the highest and lowest pan content temperatures observed.

For all tests, the hydrocarbon and alcohol sensors at sites 7, 9, and 11 reached 30% of ignition voltage from 20 to 205 seconds before ignition. For tests with the aluminum pans, 30% of ignition voltage was reached from 75 to 160 seconds before ignition while the ceramic pans did so 20 to 105 seconds before ignition. Results for stainless steel were closer to those for aluminum pans with 30% of ignition voltage occurring from 75 to 205 seconds before ignition.

A plot of sensor voltage is shown in Figure 10.2A (for aluminum pan tests). Note that tests 27 and 28 showed that the sensor response was low and variable even at 120 seconds prior to ignition. A plot of sensor voltage for ceramic pans is shown in Figure 10.2B. Note the difference in the baseline voltage and the lack of response 120 seconds prior to ignition in Test

19. Figures 10.2A and 10.2B show that sensor responses with low oil volumes occur only near ignition.

An important factor in the variation in pan content temperature is the amount of oil. A volume of 30 ml does not provide uniform coverage of the pan floor. The oil tends to form puddles or droplets rather than a uniform film on the pan floor. The pan content thermocouple is not always completely immersed in the oil. Thus the thermocouple may be reading a combination of the temperatures of the pan floor, oil, and air surrounding the thermocouple bead. Figure 10.2C illustrates the above (note test 27's pan content temperature's uneven response).

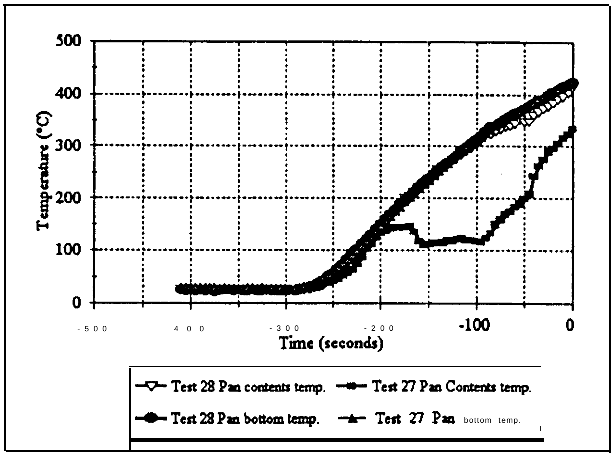

Figure 10.2C: Tests 27 and 28. Test scenario -- 30 ml of soybean oil heated on the high setting using a 10" (254 mm) diameter heavy aluminum pan. Pan content and pan bottom temperatures plotted against time.

Overall, the 30 ml of oil tests produced variable and low sensor responses presumably due to relatively low vapor concentrations generated. Responses also varied among the ceramic, stainless steel, and aluminum pan tests. Unreliability of pan content temperatures was a characteristic of the 30 ml of oil tests. These latter observations probably reflected the inability of this small volume of oil to cover the pan floor. The pan bottom temperatures for the ceramic pans were lower than the pan content temperature due to poor conductivity. Poor conductivity issues are discussed further in section 10.5.2.

0.3 THERMAL INERTIA

A series of tests were performed on an open coil electric range to evaluate the effects of thermal inertia, i.e., the residual heat transfer from a de-energized heating element. Tests were performed using an empty pan, 100 ml of oil, and 500 ml of oil. This phenomenon does not occur with gas ranges (a significant residual heat source does not exist for gas ranges after shut off). As discussed in the previous section, a volume of 100 ml (instead of 30 ml) of soybean oil was chosen because it provided uniform coverage in a 10 inch (254 mm) pan. All tests were performed in duplicate using 10 in (254 mm) diameter stainless steel frying pans.

For the empty pan tests, a pan was heated on the high setting until the pan content temperature reached 380°C (716°F) (i.e., pre-ignition temperature); then, the range coil was turned off. For the 100 ml soybean oil tests, the oil was heated on the high setting until it reached 260°C (500°F) or 330°C (626°F). A shut off temperature of 330°C (626°F) was chosen for the 100 ml tests because ignition occurred in a preliminary 100 ml test run when the coil was turned off at an oil temperature of 360°C (680°F). For 500 ml of soybean oil tests, the oil was heated on the high setting until it reached either 260°C (500°F) or 360°C (680°F).

The results for these tests are presented in Table 10.3A. The values for maximum oil temperature during the course of each test, maximum pan bottom temperature, time to reach maximum food temperature after shutoff time, and the increase in temperature after shut off are presented.

The results from the 100 ml and 500 ml oil tests showed that the smaller the volume of oil, the larger the temperature rise after the heat is shut off. Turning the heat off when the oil reached 260°C (500°F) resulted in an average temperature increase of 50°C (90°F) for 100 ml of oil and 34°C (61 °F) for 500 ml of oil. The temperature rise, however, decreased as the shut off temperature was increased. Turning the heat off when the oil reached 330°C (626°F) or 360°C (680°F) for 100 ml or 500 ml of oil, respectively, resulted in a average temperature increase of 3 1°C (56°F) for 100 ml of oil and 16°C (29°F) for 500 ml of oil.

The reason for the differences observed with the two oil volumes is mostly related to the fact that the specific heat capacity of the heating coil is fixed. Thus, as the oil volume is increased, the degree of temperature rise would decrease. For volumes of oil less than 100 ml, thermal inertia effects could be greater.

Table 10.3A: Thermal inertia data

Test number	Amount of oil (ml)	Pan content Shutoff Temperature (°C)	Time after shut off to reach max. oil temp (sec)	Max. Pan Content Temp. (°C)	Max. Pan Bottom Temp (°C)	Pan content temp. Increase after shut off (°C)	Temperature difference (max pan bottom - max oil temp)
89	Empty	380	10	377.5	633.0	2.3	255.5
90	Empty	380	20	384.4	618.7	2.2	234.3
91	100	260	65	308.25	320.0	48.2	11.8
92	100	260	70	312.1	318.0	52.1	5.9
93	100	330	45	364.7	372.3	34.7	7.6
94	100	330	40	357.9	371.9	27.9	14.0
69	500	260	105	291.9	335.5	31.9	43.6
70	500	260	110	295.9	358.2	35.9	62.3
71	500	360	70	371.2	425.7	11.2	54.5
72	500	360	55	381.1	423.1	21.1	54.5
All tests were performed with the right front large heating element with the heat setting at high.							

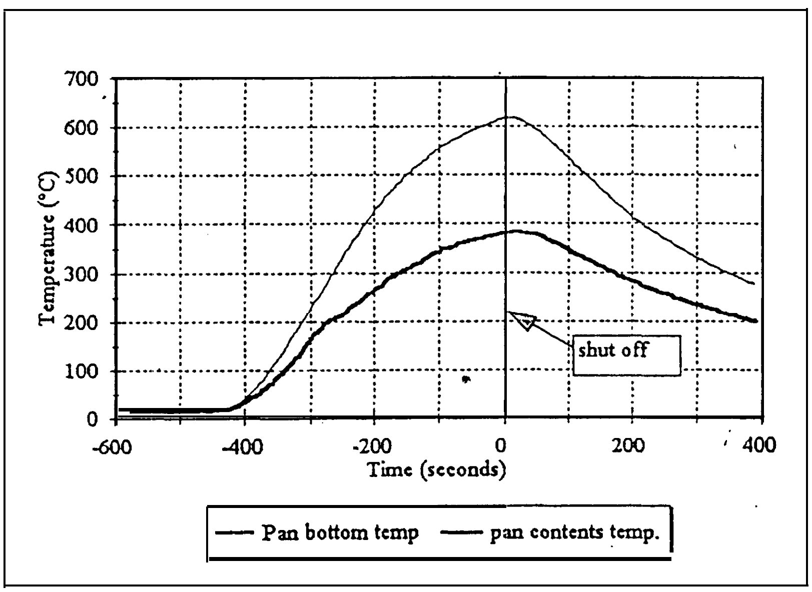

Figure 10.3A: Test 90; Test scenario -- Thermal inertia test with an empty 10" diameter stainless steel pan at a high heat setting. Pan bottom and pan content temperature responses plotted against time.

The time to reach maximum oil temperature after shut off is generally greater with larger volumes of oil. Turning the heat off when the oil reached 260°C resulted in an average time to maximum temperature after turning the heat off of 68 seconds for 100 ml of oil and 107 seconds for 500 ml of oil. Turning the heat off when 100 ml of oil reached 330°C or 500 ml of oil reached 360°C, resulted in an average time to maximum. temperature after turning the heat off of 42 seconds for 100 ml of oil and 62 seconds for 500 ml of oil.

In the two empty pan tests, practically no increase in pan content temperature occurred after shut off (2.2°C to 2.3°C [4 to 4.1°F]) since the pan rapidly lost heat to the air. Figure 10.3A shows a graph of the pan content thermocouple and pan bottom thermocouple responses plotted against time in an empty pan test.

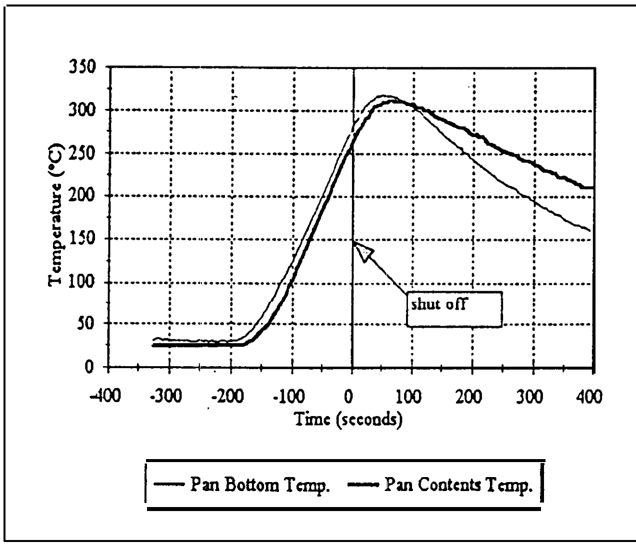

Figure 10.3B: Test number 92; Test scenario -- 100 ml of soybean oil heated on high on a 10" diameter stainless steel pan. Range turned. off at a pan content temperature of 260°C (500°F). Pan content and pan bottom temperatures plotted against time.

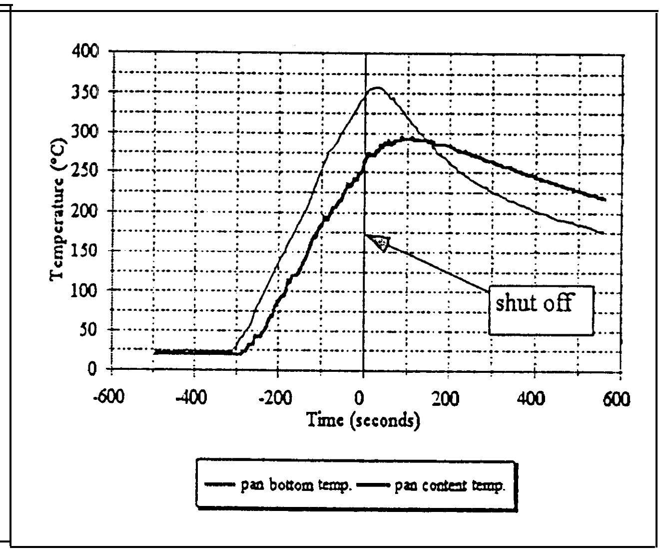

Figure 10.3C: Test number 70; Test scenario -- 500 ml of soybean oil heated on high on a 10" diameter stainless steel pan. Range turned off at a pan content temperature of 260°C (500°F). Pan content and pan bottom temperatures responses plotted against time.

Figure 10.3B shows the pan content and pan bottom temperatures for a scenario where 100 ml of oil was heated on the high setting and turned off at a pan content temperature of 260°C (500°F). The pan content temperature rise after shut off is approximately 50°C (90°F). The difference between the two temperature curves is small up to 100 seconds after shut off. Figure 10.3C shows the pan content and pan bottom temperatures for a scenario where 500 ml of oil was heated on the high setting and turned off at a pan content temperature of 260°C (500°F). The pan content temperature increase with a larger volume of oil (500 ml) is less than that observed with the 100 ml test even though the difference in the two temperature curves is larger than the difference found in the 100 ml tests. Figure 10.3D shows the pan content and pan bottom temperatures for a scenario where 100 ml of oil was heated on the high setting and turned off at a pan content temperature of 330°C (626°F). Once again, t'he temperature difference between pan bottom and content is small and the increase in oil temperature is lower than that observed in the 260°C (500°F) shut off scenario. Figure 10.3E shows the pan content and pan bottom temperatures for a scenario where 500 ml of oil was heated on the high setting and turned off at a pan content ternperature of 360°C (680°F). The difference in pan bottom and pan content temperature is greater than for 100 ml of oil at 360°C (680°F), while the increase in pan

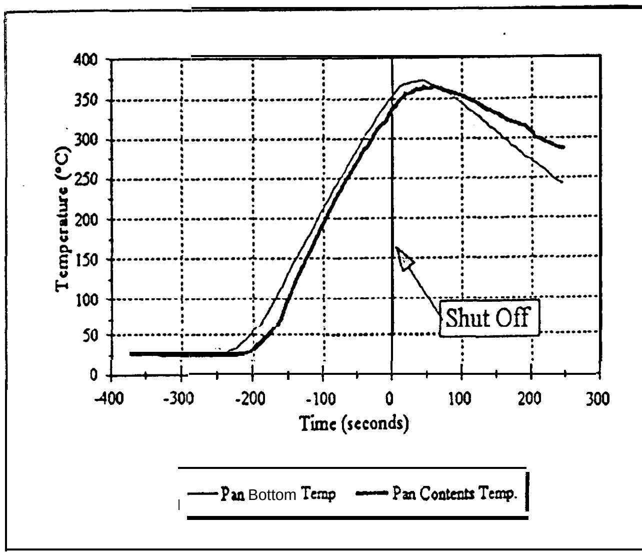

Figure 10.3D: Test 93; Test scenario -- 100 ml of soybean oil heated on high on a 10" diameter stainless steel pan. Range turned off at a pan content temperature of 330°C (626°F). Pan content and pan bottom temperature responses plotted against time.

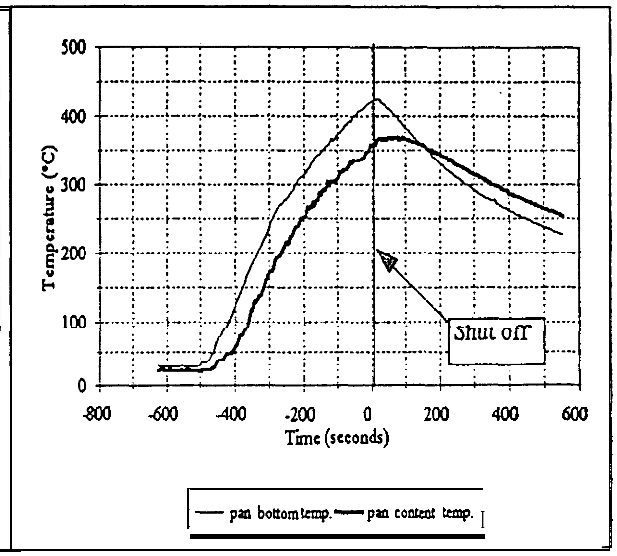

Figure 10.3E: Test 71; Test scenario -- 500 ml of soybean oil heated on high on a 10" diameter stainless steel pan. Range turned off at a pan content temperature of 360°C (680°F). Pan content and pan bottom temperature responses plotted against time.

content temperature is less. These observations are consistent with the ability of the smaller oil volume to be more rapidly heated by a fixed heat source. In choosing a cutoff temperature to prevent ignition, the effects of thermal inertia must be considered especially with smaller volumes of oil where the pan content and bottom temperatures are quite close.

10.4 TEMPERATURE DATA AT IGNITION

This section analyzes the temperatures at ignition and considers a thermal inertia limit for evaluating the performance of the other detection devices in subsequent sections. This limit represents 99% probability of avoiding ignition based on the tests conducted. The 41 tests that achieved ignition with metal pans are shown on Table 10.4A. Pan bottom temperatures ranged from 334°C to *494°C (633* to 921°F) for all ignition scenarios. For oil scenarios, the pan bottom temperature ranged from 386°C to 494°C (727 to 921°F). Pan content temperatures ranged from 288°C to 410°C (550 to 770°F) for all scenarios. For oil only, temperatures ranged from 346°C to 410°C (655 to 770°F). The lowest pan content and bottom temperatures were achieved with the caramelized sugar tests (tests 15 and 16). The sugar in one of the two tests bubbled out of the pan and ignited when it contacted the burner; the bubbling sugar ignited in the other test without contacting the burner. The data in Table 10.4B show that the pan bottom temperatures are relatively consistent, regardless of pan metal material, air flow effects, or pan position. The mean pan bottom temperature was 438°C (820°F) with a standard deviation of 30°C (54°F) while the mean pan content temperature was 391°C (736°F) with a standard deviation of 30°C (54°F).

Based on the data in Table 10.4B (which follows a normal distribution), a pan content temperature of about 300°C (572°F) represents a 99% probability [$\bar{x}$ - 3s (mean minus three standard deviations)] of not achieving ignition. This temperature is not unrealistic considering that one of the caramelized sugar tests ignited below 300°C (572°F). When the caramelized sugar tests are not considered in the above calculations, the 99% value is 309°C (588°F). While exclusion of small oil volume tests raises the $\bar{x}$ -3s value for the pan content temperature to 35 1 °C (664°F), the pan bottom temperature would also be elevated by 25 to 30°C (45 to 54°F) in either exclusion data set. Since there is not at present a reason to exclude any data set, all test data will be uskd in estimating the temperature to ensure a 99% probability of not reaching ignition. Also, the percentages of the coefficient of variation ($s/\bar{x}$) are under 10%, showing that the standard deviation is small relative to the mean. Figure 10.4A illustrates graphically the consistency of data. The one data point that falls below the error band in Figure 10.4A is one of the two caramelized sugar tests. The 30 ml oil tests showed the greatest variation in pan content temperatures probably because of oil puddling.

The above information provides a basis for examining the performance of gas sensors and smoke detectors when the pan bottom temperature reaches 340°C (644°F). The Underwriters' Laboratories Standard 1083 Household Electric Skillets and Frying-Type Appliances states in the Performance section, Normal Temperature subsection 27.5 states that *"In an appliance that can hold an appreciable quantity of oil, fat or grease during the cooking operation, the maximum and average temperatures measured at the center of the cooking surface shall not be higher than 300" C (572° F), and 260° C (500° F), respectively. These temperatures are to be measured after a stabilized cycling pattern has been established. The temperature at any point on the cooking surface shall not exceed 390" C (734" F) at any time during the test."*

Section 1.2 of the standard states the following: *"This standard applies to frying-pans, sauce-*

pans, griddles, deep-fat-fryers, waffle **and sandwich makers, and** *other similar appliance which may or may not be thermostatically* **controlled.** *"* Additionally, Good Housekeeping staff suggested that practically all foods can be readily cooked at a maximum temperature of

Table 10.4A: Pan bottom and pan content temperatures at ignition for metal pan tests

Test number	Pan Bottom Temperature at Ignition (°C)	Pan Content temperature at Ignition (°C)
1	385.7	365.25
2	433.7	380.5
5	453.56	406.29
6	466.72	419
7	447.96	376.84
8	440.74	376.52
9	409.24	361.58
10	415.61	373.74
11	434.13	385.54
12	456.17	410.75
13	400.62	391.44
14	401.18	395.86
15	334.46 **	310.3 **
16	360.37 **	288.57 **
27	442.16 *	345.82 *
28	424.18 *	413.78 *
29	418.74 *	426.52 *
30	436.4 *	439.86 *
31	419.13	383.2
32	428.49	393.22
38	429.21 *	426.87 *
39	452.77 *	426.87 *
40	457.51 •	[illegible] *
45	449.86	393.78
46	455.27	393.53
47	446.13	386.04
48	445.92	382.9
49	466.53	399.7
50	462.76	399.46
51	450.2	380.38
52	457.9	393.23
53	451.2	395.71
54	438.4 *	389.32
55	480.3	379.97
56	451.2	380.71
57	460.2	390.85
58	449.16	379.71
59	493.71	399.87
60	455.8	398.01
61	448.01	409.97
62	456.7	398.4

* pan contents: 30 ml oil
** pan contents: 227 grams of sugar
Tests 45 through 48 are pan position tests
Tests 49 through 62 are air flow tests

Table. 10.4B: Statistics on the pan bottom and pan content temperatures at ignition

	Pan Bottom Temperature at Ignition (°C)	Pan Content Temperature at Ignition (°C)	Excluding caramelized sugar tests		Excluding 30 ml and caramelized sugar tests	
			Pan Bottom Temperature at Ignition (°C)	Pan Content Temperature at Ignition (°C)	Pan Bottom Temperature at Ignition (°C)	Pan Content Temperature at Ignition (°C)
Mean ($\bar{x}$)	438.3	390.7	443.1	395.5	444.3	390.0
Standard Deviation (s)	30.5	30.2	22.4	28.9	23.9	12.9
$\bar{x}$ - 3s probability value	346.8	300.1	375.9	308.8	372.6	351.3
Coefficient of variation (s/$\bar{x}$)	6.96 %	7.73 %	5.05%	7.31%	5.37%	3.31%

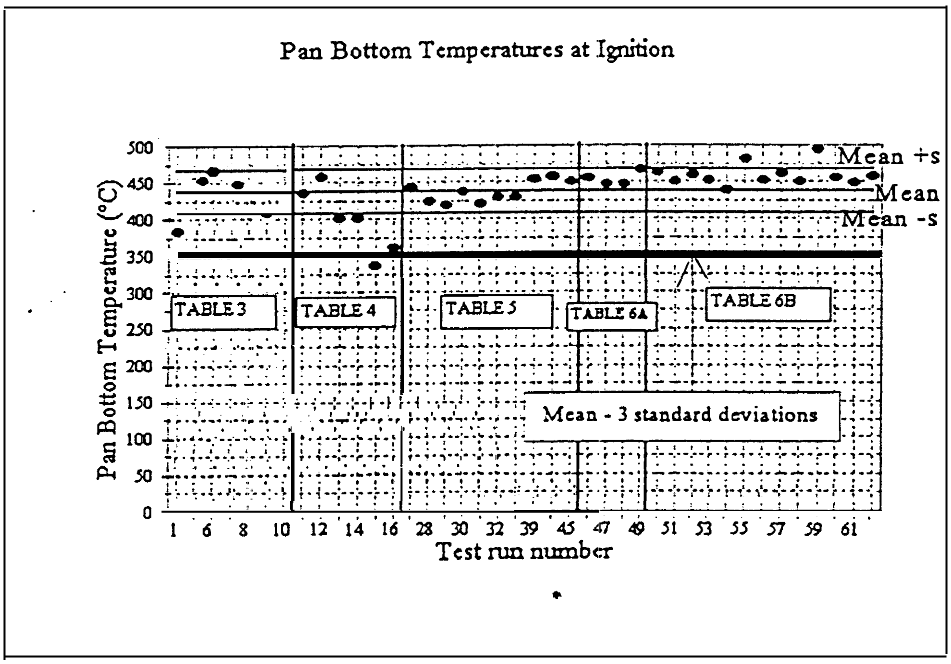

Figure 10.4A: Plot of pan bottom temperatures at ignition for metal pan tests.

550°F (288°C). Thermal inertia data from section 10.3 further supports the choice of a pan content temperature of around 300°C (572°F) or a pan bottom temperature of 340°C (626°F) (i.e., after consideration of thermal inertia). One of the thermal inertia tests also justified a pan bottom temperature of around 340°C.(626°F). In this test,, 100 ml of soybean oil was heated on high on a 10" (254 mm) diameter stainless steel pan and ignited after being shut off at an oil temperature of 360°C (680°F). Based on these findings, a number of detection devices in the following sections will be examined at pan content temperatures around 300°C (572°F) to determine how they function.

10.5 EFFECT OF HEAT SETTINGS. PAN MATERIALS. AND THERMOCOUPLE POSITION

10.5.1 Effect of Heat Settings and Pan Materials on 500 ml Soybean Oil Scenarios

A series of tests was conducted to examine the effects of heat settings and pan materials using 500 ml of soybean oil. The descriptions of these tests are presented in Table 10.5.1A. Each test was performed in duplicate using 500 ml of soybean oil in stainless steel, heavy aluminum, and ceramic (glass) pans. Tests were conducted at either medium high or high heat settings using the right front (large) open coil burner of the electric range.

All high heat tests produced ignitions. None of the medium-high heat tests produced ignitions. After the first medium-high heat tests resulted in the non-ignition (at equilibrium, i.e., 10 minutes at a steady state temperature ±4°C), the remainder of non-ignition tests were run for a shorter time after steady state was achieved. At least one of each test on each different pan type was allowed to proceed to steady state.

Table 10.5.1A: Test Names and Cooking Scenario Descriptions for the 500 ml Heat Setting and Pan Material Tests - All Performed on an Electric Open Coil Stove

Test Numbers	General Procedure	Pan Material
7 & 8	**Place frying pan on large front burner and heat on high until ignition (Baseline Cooking Scenario for High Heat Test)**	stainless steel
31 & 32	Place frying pan on large front burner and heat on high until ignition	heavy aluminum
21 & 22	Place frying pan on large front burner and heat on high until ignition	transparent ceramic
43 & 44	Place frying pan on large front burner and heat on medium-high until ignition **(Baseline Cooking Scenario for Medium-High Heat Test)**	stainless steel
35 & 36	Place frying pan on large front burner and heat on medium-high until ignition	heavy aluminum
25, 26 & 75	Place frying pan on large front burner and heat on medium-high until ignition	transparent ceramic
all tests used 10 in (254 mm) diameter pans		

The following abbreviations are used in the tables throughout this and other sections:

- Gen Hy: General Hydrocarbon Sensor
- Gen Al: General Alcohol
- Cook Alc : Cooking Alcohol Sensor
- Tot Ck: Total Cooking Sensor
- S7: Site 7 (located on the wall between the range hood and top of the stove)
- S9: Site 9 (located on the front of the range hood in the center).
- S 11: Site 11 (located on the ceiling over the front of the center of the stove)

The initial signals for all sensors used in the analysis were taken at 60 seconds after data acquisition began and before the range was energized. This time was chosen in order to evaluate the stability prior to the heating of the oil. The gas sensor voltages were examined at a pan content temperature of 288°C (550°F) for the reasons described in section 10.4 and compared with the initial sensor voltage.

General hydrocarbon and cooking alcohol sensor data were examined at sites 7, 9, and 11. Figure 10.5.1A shows that the general hydrocarbon sensors were the most responsive (4 V fi-om baseline to ignition) at site 7 to the gases produced a pan content temperature of 288°C (550°F). The cooking alcohol, total cooking, and general alcohol sensors have lesser signals (approximately 2 V from baseline to ignition) at 288°C (550°F). This reflects both the relatively low level of cooking gases at this temperature as well as a weak plume.

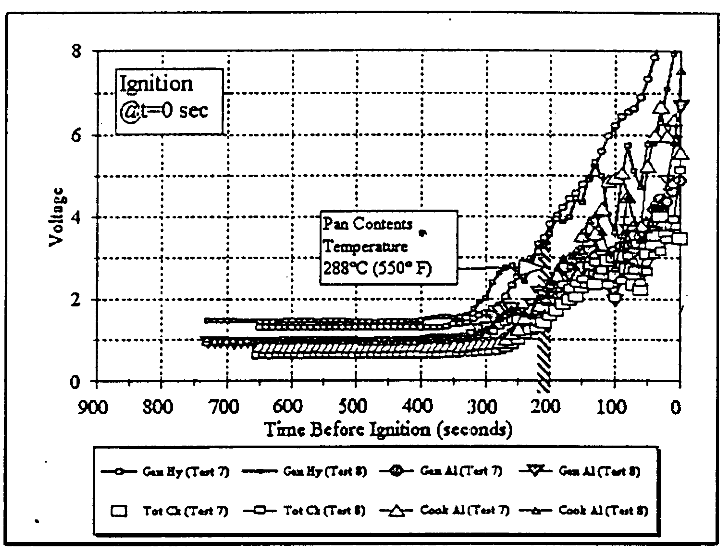

Figure 10.5.1A: Gas sensors' output voltages at site 7 for 500 ml of soybean oil in a 10 in (254 mm) diameter stainless steel pan at the high heat setting

Table 10.5.1B presents the changes in sensor voltage when the pan content temperature is 288°C (550°F). At site 7, the general hydrocarbon sensor produced the greatest voltage changes for the high heat tests with the stainless steel pans followed by the heavy aluminum pans at the medium high heat setting. The cooking alcohol sensor responses were generally less than those of the hydrocarbon sensors for all pan types. Ceramic pans tended to have the least response for either sensor at all sites. Repeat tests for all pan types showed poor repeatability, especially at site 7 and to a lesser degree at site 9. Site 11 tests showed good repeatability, reflecting perhaps a more general mixing and spreading of the plume at this distance from the range.

Table 10.5.1B: Voltage Changes from Initial Signal to the signal at a Pan Content Temperature of 288°C (550°F) for all High and Medium-High Heat Tests

	Heat Setting	Stainless Steel	Stainless Steel	Heavy Aluminum	Heavy Aluminum	Ceramic (glass)	Ceramic (glass)	Ceramic (glass)
Gen Hy S7 (volts)	High	2.48[7]	1.69[8]	1.28[31]	0.29[32]	1.38[21]	0.05[22]	
	Medium High	1.45[43]	0.12[44]	2.29[35]	2.49[36]	-0.16[25]	1.40[75]	1.88[26]
Cook Alc S7 (volts)	High	1.48[7]	0.87[8]	0.71[31]	0.19[32]	0.32[21]	0[22]	
	Medium High	0.37[43]	0.02[44]	1.22[35]	1.32[36]	-0.23[25]	0.79[75]	1.18[26]
Gen Hy S9 (volts)	High	1.28[7]	1.01[8]	0.87[31]	0.38[32]	1.01[21]	0.04[22]	
	Medium High	0.94[43]	0.80[44]	1.32[35]	1.14[36]	0.55[25]	0.65[75]	1.18[26]
Cook Alc S9 (volts)	High	2.05[7]	1.15[8]	1.19[31]❑	0.18[32]❑	0.69[21]	-0.05[22]	
	Medium High	1.45[43]	0.64[44]	2.24[35]	2.31[36]	0.2[25]	1.28[75]	1.42[26]
Gen Hy S11 (volts)	High	0.68[7]	0.76[8]	0.61[31]	0.84[32]	0.44[21]	0.29[22]	
	Medium High	0.79[43]	0.93[44]	0.99[35]	0.83[36]	0.49[25]	0.31[75]	0.39[26]
Cook Alc S11 (volts)	High	1.17[7]	1.20[8]	1.07[31]	1.31[32]	0.69[21]	0.36[22]	
	Medium High	1.25[43]	1.38[44]	1.31[35]	1.24[36]	0.94[25]	0.64[75]	0.91[26]

❑ Test Results Not Included in the Analysis due to Malfunctioning Sensor
Superscript refers to test number.

At site 9, the strongest signals were recorded for the cooking alcohol sensor on high heat with stainless steel and medium heat for aluminum. Signals from the hydrocarbon sensors tended to be lower. Overall, the signals appeared to be somewhat lower than at site 7. However, repeatability tended to be better than at site 7. ceramic pans again had the lowest responses. At sites 9 and 11, the cooking alcohol sensor responses were somewhat higher than the general hydrocarbon sensor responses. Overall repeatability was good with response magnitudes being similar to that of site 9. Responses at all three sites were 2.5 V or less. Gas sensor responses from aluminum pan tests for medium high (non-ignition) tests were actually greater than sensor responses for high heat tests which did ignite. The medium high tests were performed longer than high heat tests and yet did not terminate in ignition. This effect was only occasionally seen with stainless steel pans, while ceramic pans exhibited mixed behavior.

The pan content and bottom temperatures at ignition or steady state are shown in Table 10.5.1C at high and medium high heat tests. None of the medium-high heat tests run with 500 ml of soybean oil went to ignition while all high heat tests did.

Table 10.5.1C: Pan Content and Bottom Temperatures at ignition for the high and medium high heat tests

Test Description		Heat Setting	Stainless Steel	Stainless Steel	Heavy Aluminum	Heavy Aluminum	Ceramic (glass)	Ceramic (glass)	Ceramic (glass)
Temperatures at Ignition	Pan Content Temperature (°C)	High	377[7]	377[8]	383[31]	393[32]	391[21]	405[22]	
		Medium High	No ignition	No ignition	No ignition	No ignition	No ignition	No ignition	No ignition
	Pan Bottom Temperature (°C)	High	448[7]	441[8]	419[31]	429[32]	403[21]	400[22]	
		Medium High	No ignition	No ignition	No ignition	No ignition	No ignition	No ignition	No ignition
Pan bottom temperature when pan content temperature is 288° C (550° F)		High	366[7]	362[8]	353[31]	352[32]	309[21]	290[22]	
		Medium High	305[43]	307[44]	298[35]	290[36]	230[23]	245[25]	243[26]

- Tests terminated prior to achieving pan bottom temperature of 288° C (550° F)

Superscript refers to test number

10.5.2 Effect of Thermocouple Position and Poor Conductive Material Pans

To better understand why the pan content temperatures were higher than the pan bottom temperatures for ceramic pans under certain conditions, a series of tests was performed on transparent and opaque ceramic pans to determine their thermal characteristics. In addition, tests with two pan content thermocouples were performed to examine the temperature distribution characteristics of the transparent ceramic and stainless steel pans. The coefficients of thermal conductivity (k) over the temperature range from 21°C to 288°C (70 to 550°F) for AISI 304 stainless steel is 14.0 (W/m•K) to 18.06 (W/m•K), for pure aluminum is 224(W/m•K) to 200(W/m•K) and for Corning 9606 is 3.98 (W/m•K) to 5.33 (W/m•K) for Corning 9606.

Table 10.5.2A: Thermocouple position and pan material test data

Test number	Pan content thermocouple location(s)	Pan Content	Heat Setting	Peak Temperatures (°C)		
				Pan Bottom	Center (floor)	2.25" Offset (floor)
	Opaque White Ceramic Pan					
76	1 Centered, 0.01" above pan floor	500 ml	med-hi	136.6	102.6	
77	1 Centered, 0.01" above pan floor	500ml 500	high	198.7	107.9	
78	1 Centered, 0.01" above pan floor	500 ml Oil	med-hi	313.9	325.9	
	Transparent Ceramic with Intact Interior Coating					
79	1 Centered, in contact with pan floor	500 ml	med-hi	174.9	102.9	
80	1 Centered, in contact with pan floor	500 ml Oil	med-hi	276.9	329.6	
81	1 Centered, in contact with pan floor	150ml Oil	med-hi	242.6	326.8	
	Transparent Ceramic with No Interior Coating					
82	1 Centered, in contact with pan floor	500 ml Water	med-hi	28.5	102.1	
83	1 Centered, in contact with pan floor	500 ml Oil	med-hi	265.3	314.5	
84	1 Centered, in contact with pan floor	150ml Oil	med-hi	267.1	344.7	
85	1 Centered, 0.01" above pan floor	500 ml Oil	med-hi	287.6	328.97	
86	1 Centered, 0.01" above pan floor	500 ml Oil	med-hi	273.7	321.1	
87	1 Centered contacting pan floor ,1 offset	150ml Oil	med-hi	334.3	355.5	374.2
	Stainless Steel					
88	1 Centered contacting pan floor and 1 offset	150ml Oil	med-hi	350.29	308.7	309.3

Note: 0.01" = 0.25 mm . 2.25" = 57 mm
All tests were performed with 10" (254 mm) diameter pans.
The oil used for these experiments was soybean oil.

The series of tests described in Table 10.5.2A, was performed with opaque white ceramic pans, transparent ceramic pans (with and without black floor coating), and stainless steel pans for comparative purposes. The open coil element electric range was used for all of the tests in this series. The medium-high heat setting was used for all except one test where the heat was set on high to determine whether heat setting has a significant influence on the test results. These tests were not part of the original CPSC plan for phase III of the range fire project.

Tests were conducted with water or soybean oil using 10" (254 nun) diameter pans. A set of tests with and without the black interior coating on the transparent pan were performed to determine if the coating could affect the conductive properties of the ceramic pans. Figure 10.5.2A shows the transparent ceramic pan with the black interior coating.

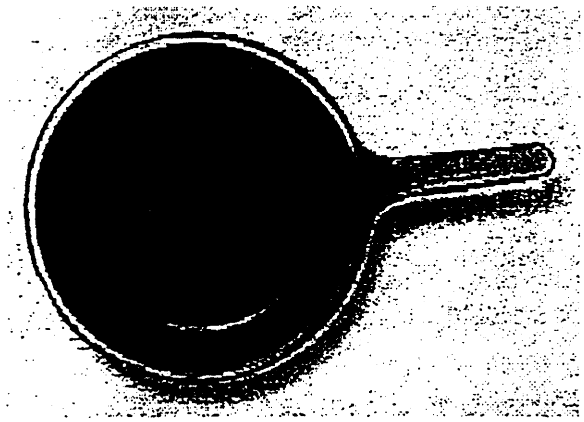

Figure 10.5.2A: Top view of an unused transparent ceramic pan.

Figure 10.5.2B shows the placement of the spring loaded pan bottom thermocouple. Pan content thermocouples in some tests were either suspended 0.010" (0.25 mm) above the pan floor or

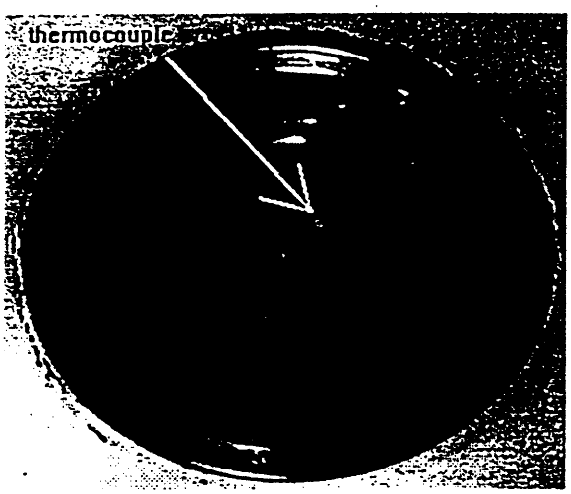

Figure 10.5.2B: Top view of large front right heating element for the open coil electric range.

placed in contact with pan floor to determine if this could affect measurement of temperature of the pan contents. Either one (Figure 10.5.2C) or two (Figure 10.5.2D) thermocouples were

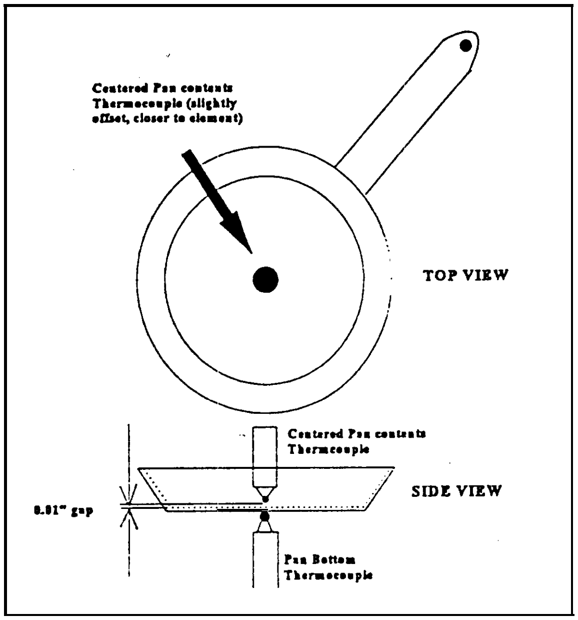

Figure 10.5.2C: Thermocouple arrangement where the pan content thermocouple is suspended 0.01" (0.25 mm)

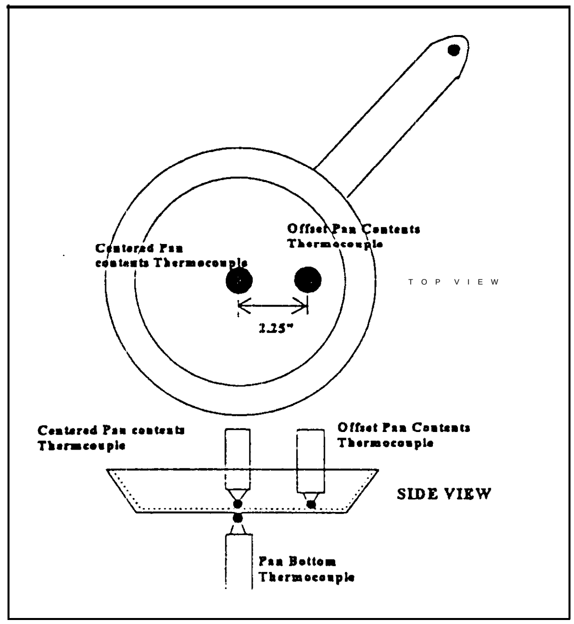

Figure 10.5.2D: Thermocouple arrangement where two pan content thermocouples were used. Note: 2.25" = 57 mm.

placed in the pan contents to determine the heat distribution characteristics with the transparent ceramic pans.

Tests with the opaque white ceramic pan (Table 10.5.2A) showed (as in the previous section) that the pan content temperature with oil is higher than the pan bottom temperature using the centered pan content thermocouple. The effect is not seen with water at either heat setting because its low boiling point limits pan content temperature. Similar results are seen with the transparent ceramic pans with or without the black interior coating for comparable tests. The transparent pans also showed that there is little overall difference in placing the center pan content thermocouple in contact with the pan floor or slightly above it. Similarly, the volume of oil (150 ml to 500 ml) did not seem to affect the results.

Offsetting the thermocouple by 2.25" (57 mm) in the ceramic pan (i.e., over the heating coils) showed that the oil close to the heating coils was heating faster. The stainless steel pan, however, showed no difference in pan content temperature distribution and has a higher pan bottom temperature. These data demonstrated the low thermal conductivity of ceramic pans. Whether this could influence ignition at a medium high heat setting is unknown. Thermocouple placement in relation to the burner is also important although contact with the pan floor is not.

The poor conductivity of ceramic pans is illustrated by plotting test runs 87 (ceramic pan) and 88 (stainless steel). Both tests used 150 ml of soybean oil with two pan content thermocouples in the oil and one pan bottom thermocouple. One pan content thermocouple is placed near the center of the pan over the pan bottom thermocouple and the second is offset 2.25" (57 mm) to the right of the center thermocouple (Figure 10.5.2D). The plot in Figure 10.5.2E shows that the stainless steel pan had pan bottom temperatures higher than the pan content temperature (the offset and centered pan content temperature curves overlap each other).

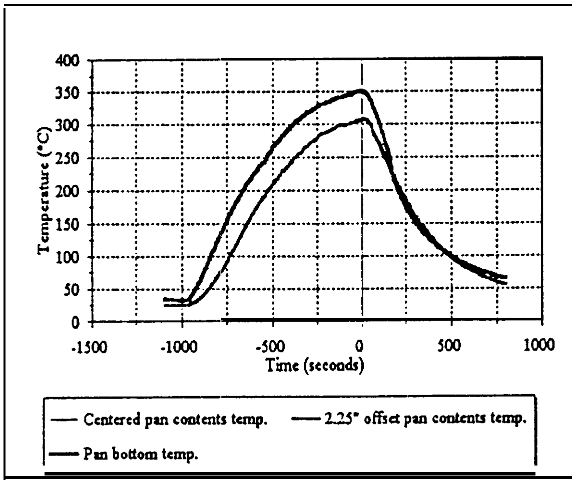

Figure 10.5.2E: Test number 88; test scenario -- 150 ml of soybean oil heated on a medium high heat setting in a stainless steel 10" diameter pan. Pan bottom, centered pan contents, and offset pan content temperatures plotted. against time.

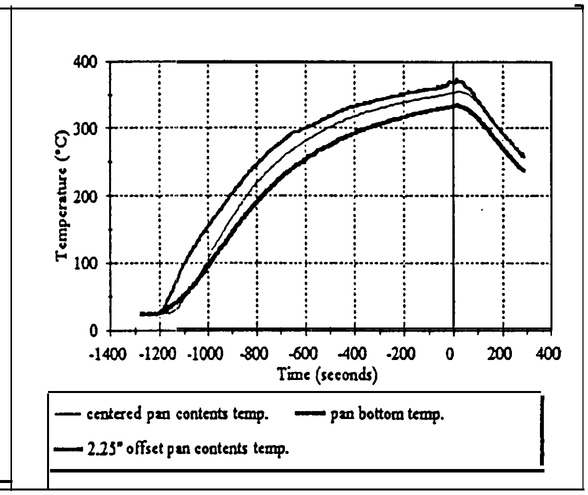

Figure 10.5.2F: Test 87; test scenario -- 150 ml of soybean oil heated on the medium high heat setting in a 10" diameter pan without the interior coating. Pan bottom, centered pan content, and offset pan content temperatures plotted against time.

Additionally, the pan contents had the same temperature curve whether the content thermocouple was centrally located or offset showed the same temperature. In contrast, the ceramic pan showed a non-uniform temperature distribution of pan contents with the pan contents being at a higher temperature than the pan bottom (Figure 10.5.2F). The pan contents temperature came within 20°C of each other while the pan bottom temperature was 40°C lower than the offset content temperature.

Thermocouple placement in relation to the burner is clearly important with ceramic pans. The pan content temperature can be up to 77°C (171°F) higher (Table 10.5.2A) than the pan bottom temperature at medium-high heat using ceramic pans. Additional study is needed to better understand pre-ignition temperatures for this type of pan using various thermocouple placements, oil volumes, and heat settings. Data presented in the previous section (Table 10.5.1C) do not indicate that the oil temperatures at ignition are different for high heat tests from stainless steel, aluminum, or ceramic pans (although ceramic pan bottom temperatures are lower).

10.6 EFFECT OF CHANGES IN AIR FLOW AND PAN POSITION

To examine the effects of changing air flows on signals produced by various sensors, studies were performed using a range hood, a ceiling fan, and a range with a down draft vent. The range hood and down draft were vented outside the kitchen. Each test was performed in duplicate using either the front or rear burner. A total of 14 tests were performed. All the tests used 500 ml of soybean oil and proceeded to ignition. The test descriptions are shown in Table 10.6A.

Table 10.6A: General Cooking Procedures and Test Names

Test Nos.	General Procedure
7 & 8	Place frying pan on large front burner and heat on high until ignition [a,c] **(Baseline Cooking Scenario Front Burner)**
45 & 46	Place frying pan on large rear burner and heat on high until ignition [a,c] **(Baseline Cooking Scenario Rear Burner)**
49 & 50	Turn ceiling fan on highest speed. Turn range hood on highest setting. Place frying pan on large front burner and heat o high until ignition [a,c]
51 & 52	Turn ceiling fan on highest speed. Turn range hood on highest setting. Place frying pan on large rear burner and heat on high until ignition [a,c]
53 & 54	Turn ceiling fan on highest speed. Place frying pan on large front burner and heat on high until ignition [a,c]
55 & 56	Turn ceiling fan on highest speed. Place frying pan on large rear burner and heat on high until ignition [a,c]
57 & 58	Turn range hood on highest setting. Place frying pan on large rear burner and heat on high until ignition [a,c]
59 & 60	Turn range hood on highest setting. Place frying pan on large front burner and heat on high until ignition [a,c]
61 & 62	Turn down draft blower on highest setting. Place frying pan on large rear burner and heat on high until ignition[b,c]

Superscripts for table 10.6A:
a. Electric Open Coil
b. Electric Down draft vent
c. 500 ml of Soybean Oil in a 26 cm (10 in) diameter stainless steel frying pan

Figure 10.6A shows the large decrease in signal voltage changes for the general hydrocarbon and cooking alcohol sensors for site 7 (rear wall) when the pan contents reached 288°C (550°F) on the front burner. The values shown are averages from the duplicate test runs. Cooking on the front burner with the use of a range hood, ceiling fan or both reduced the voltage change for the general hydrocarbon and cooking alcohol sensors to almost zero.

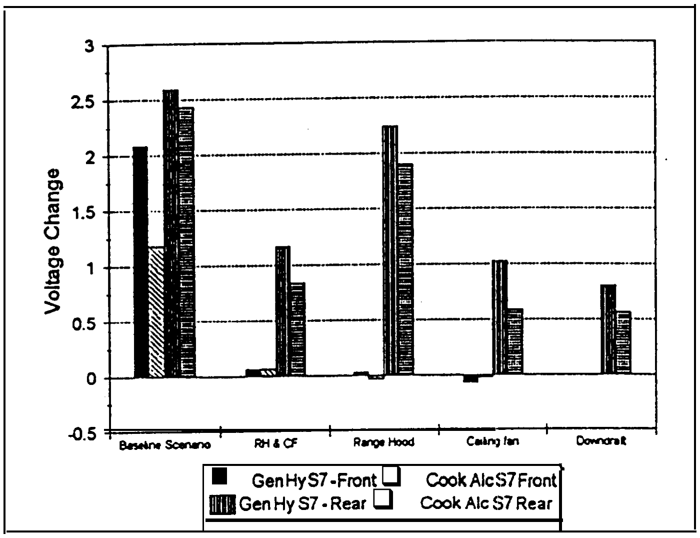

Figure 10.6A: The average change in gas sensor signals for site 7 Sensors when the pan content temperature is 288°C (550°F). All tests in Table 10.6A are included. Note: RH & CF = range hood and ceiling fan.

When the pan is placed on the rear burner, the range hood alone had a relatively little effect on sensor voltage change (since the sensors are on the rear wall) at site 7. Use of either the ceiling fan or the down. draft range, however, reduced sensor response to 20 to 40% of the baseline tests at a pan contents temperature of 288°C (550°F). The sensor responses were similarly reduced at ignition when either the ceiling fan or range hood was used.

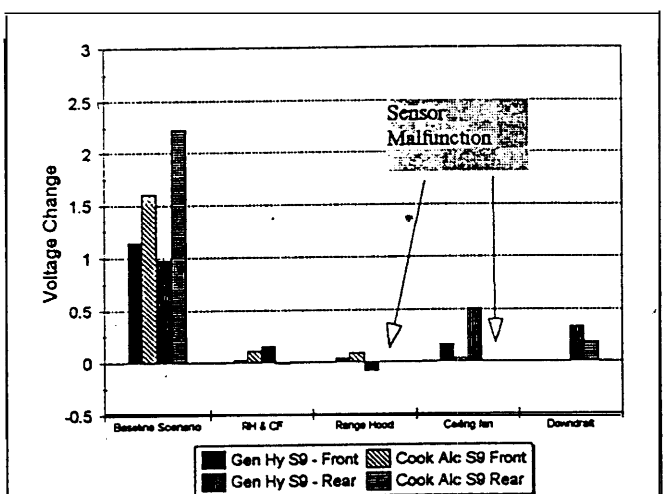

Figure 10.6B: The Average Change in Gas Sensor Signal when the pan content temperature is 288°C (550°F) for Site 9 Sensors. All Tests Included. Sensor Malfunction Refers to Results that were not analyzed.

Figure 10.6B shows the effects of the use of the hood, ceiling fan, or down draft range on voltage changes for the general hydrocarbon and cooking alcohol sensors for site 9 (front of range hood) when the pan contents have reached 288°C (550°F). The values in Figure 10.6B are averages of duplicate test runs. All changes in air flow caused a substantial reduction in sensor voltage whether the pan is placed on the front or rear burner. When testing was conducted on the rear burner, with the air flow devices operating, the sensor voltage change at site 9 decreased to 0 to 28% of the rear burner baseline scenario. Two tests showed negative voltage changes and several approached zero. Changes in air flow caused a reduction in sensor voltage changes greater than those at site 7.

The effect on sensor voltage changes for the general hydrocarbon and cooking alcohol sensors at site 11 (on ceiling above the range) were present whether the pan was on the front or rear burner (Figure 10.6C). The degree of reduction relative to the baseline tests was the least at sites 7 and 9. A cooking alcohol sensors placed in the down draft vent did not show nearly as great a reduction as seen for sensors at sites 7, 9, and 11.

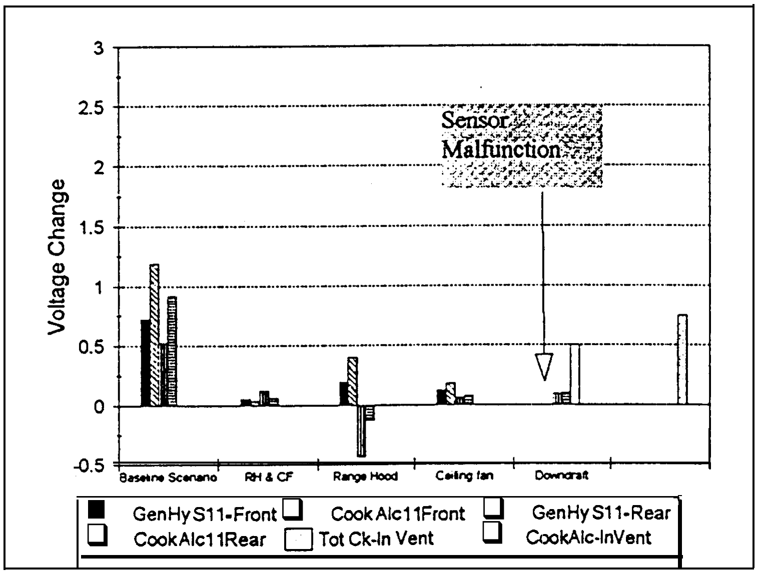

Figure 10.6C: The Average Change in Gas Sensor Signal when the pan content temperature is 288°C (550°F) for Site 11 Sensors. All Tests Included.

The data presented in Figures 10.6A through 10.6C are tabulated in Table 10.6B. Superscripts indicate test numbers. The overall changes in voltage are less than 3V in baseline tests (0.41 to 3.18 V). With the exception of rear burner tests at site 7, use of range hood, ceiling fan, or down draft range severely diminished sensor voltage changes.

Table 10.6B: Voltage changes from initial signal to the signal at the-pan content temperature of 288°C (550°F) for all test on the front and rear burners

TEST DESCRIPTION		Baseline Scenario	Baseline Scenario	R. H. & C.F.■	R. H. & C.F.■	Range Hood	Range Hood	Ceiling Fan	Ceiling Fan	Down draft	Down draft
Gen Hy S7 Volts▲	Front	2.48’	1.69’	0.09[49]	0.04[50]	0.05[59]	-0.01[60]	-0.145’	0[54]		
	rear	3.18[45]	2.01[46]	1.08[51]	1.26[52]	2.43[57]	2.06”	1.02[56]	1.02”	1.04	0.57
Cook Alc s7 Volts▲	Front	1.48[7]	0.87’	0.12[49]	0.01[50]	0.01[50]	-0.04[60]	-0.02[54]	-0.02[54]		
	rear	2 . 4	3 ”*	0.84[51]	*	•	1.76”	*	0.59[56]	0.57	*
Gen Hy S9 Volts ▲	Front	1.28[7]	1.01[8]	0.04[49]	0[50]	0[50]	0.04[60]	0.11[53]	0.21[54]		
	rear	1.17[45]	0.79[46]	0.07[51]	0.22[52]	0.22[52]	-0.19“	*	0.5”	0.30	0.36
Cook Alc S9 Volts▲	Front	2.05’	1.15’	0.17[49]	0.04[50]	0.04[50]	0.0560	-0.05[53]	0.11[54]		
	rear	2.2”	*	-0.01[51]	•	*	•	*	[illegible]	0.18	•
Gen Hy S11 Volts▲	Front	0.68’	0.76’	0.05[49]	0[50]	0[50]	0.25[60]	0.13”	0.11[54]		
	rear	0.63”	0.41[46]	0.01”	0.23”	0.23”	-0.44”	*	0.06[56]	0.09	0.10
Cook Alc S11 Volts ▲	Front	1.17’	1.20[8]	0.09[49]	-0.02[50]	-0.02[50]	0.52[60]	0.14[53]	0.21”		
	rear	0.92[45]	*	0.05”	•	•	-0.3”	*	0.08[56]	0.11	0.10
Tot Ck Volts A	Front									0.61	0.38
Cook Alc Volts▲	Rear									0.88	0.61

- Sensor Malfunction ..etc
- ■ R.H & C.F. = Range Hood and Ceiling Fan Test**
- ▲ Superscript Refers to Test Number, See Table 8.0A

Table 10.6C shows that for electric open coil range rear burner tests at ignition, the pan bottom temperatures for all baseline and air flow rear burner tests are within 14°C (25°F), while for the front burner the difference is 53°C (95°F). The pan content temperatures for rear burner tests are within 30°C (54°F) of each other at ignition, while for the front burner tests the difference is 23°C (41°F).

Room temperature at time of test did not seem to affect either the pan content or pan bottom temperatures at ignition. The down draft tests had longer ignition times than the other air flow tests did. The use of the range hood did not affect time to ignition while the use of the ceiling fan might have slightly decreased ignition times.

Table 10.6C: Ignition, pan content and pan bottom temperatures differences for the air flow and pan position tests

Test Description	Pan Position	Baseline Scenario	Baseline Scenario	RH and CF	RH and CF	Range Hood	Range Hood	Ceiling Fan	Ceiling Fan	Down Draft	Down Draft
Pan Bottom Temperature At Ignition (“C)	Front	448[7]	441[8]	467[49]	463[50]	494[59]	456[60]	451[53]	468[54]		
	Rear	*	455[46]	450[51]	458[52]	460[57]	449[58]	*	451[56]	448	457
Pan. Content Temperature at Ignition (°C)	Front	377[7]	377[8]	400[49]	400[50]	400[59]	398[60]	396[53]	389[54]		
	Rear	*	394[46]	381[51]	393[52]	391[57]	380[58]	*	381[56]	410	398
Ignition Times (seconds)	Front	550	630	593	597	636	600	539	530		
	Rear	•	570	546	599	524	548	522	530	682	785
Room Temperature (°C)	Front	27[7]	26[8]	8[49]	8[50]	9[59]	10[60]	19[53]	18[54]		
	Rear	*	14[46]	9[51]	9[52]	21[57]	21[58]	*	13[56]	12	12
Pan bottom temperature (°C)#	Front	366[7]	362[8]	362[49]	358[50]	377[59]	373[60]	356[53]	354[54]		
	Rear		366[46]	368[51]	362[52]	366[57]	367[58]	*	363[56]	355	343

= pan bottom temperature when pan content temperature is 288°C (550°F).

▸Difference Between Pan Bottom and pan content temperature (PB-PC)
• Problem Test Removed
■ R.H & C.F. = Range Hood and Ceiling Fan Test
▲ Superscript Refers to Tests Number, See Table 10.6A

The pan bottom temperatures when the oil temperature is 288°C (550°F) are within 23°C (42°F) for all the front burner tests and within 6°C (11°F) for all the rear burner tests.

Figure 10.6D shows that the pan bottom temperatures are not affected appreciably by air flow and are within 53°C (95°F) of each other at ignition. The time at which pan content temperatures reach 288°C (550°F) varies between 180 to 290 seconds before ignition.

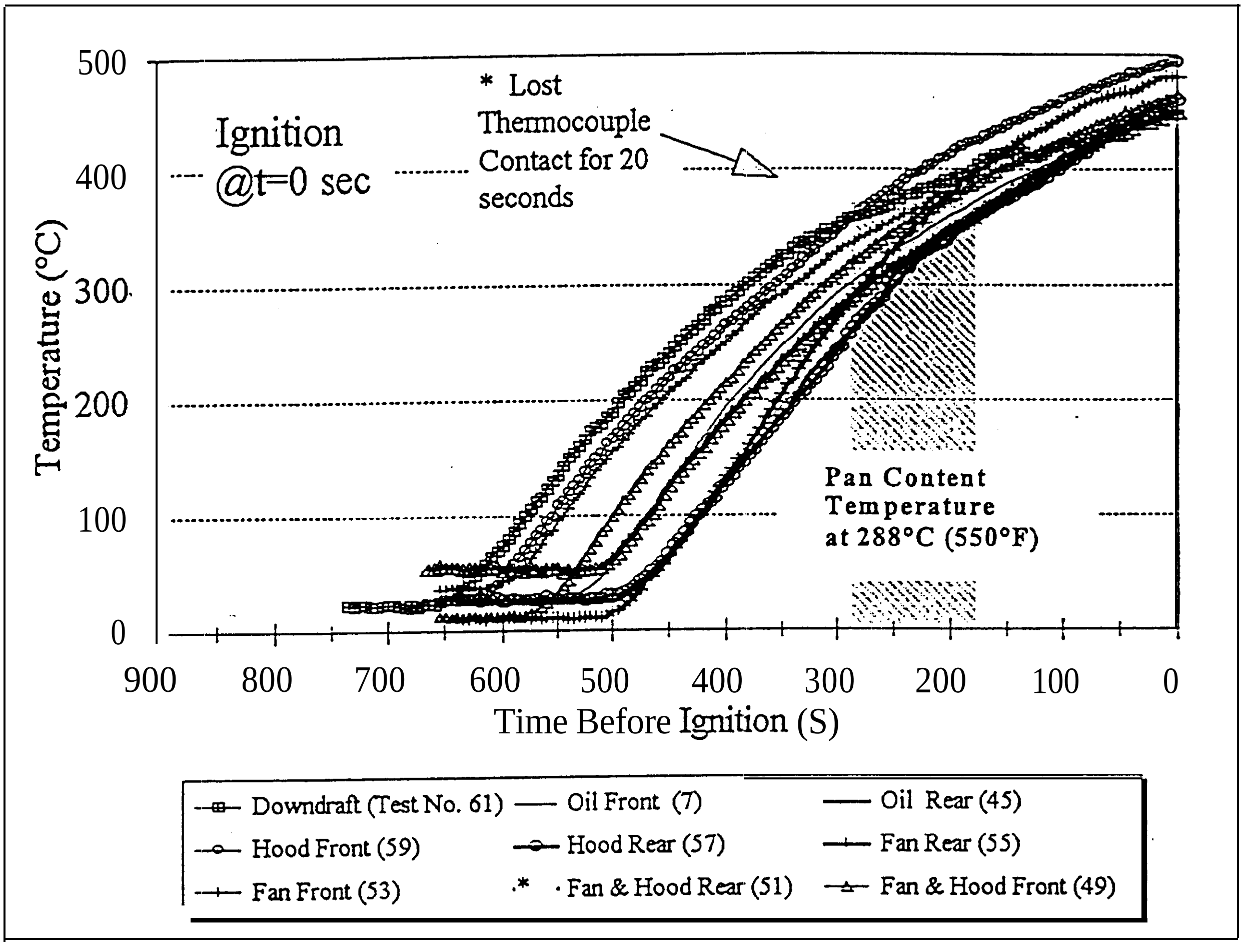

Figure 10.6D: Pan bottom temperatures for air flow tests

In summary, the air flow from range hood, ceiling fan, or down draft range caused decreases in gas sensor readings. Air flow had little or no effect on pan bottom or pan content temperatures. Sensors placed in the vents of the down draft range performed better than those above the range. Although these results are quantitatively more severe than those obtained by NIST using a range hood, the difference in data between NIST and CPSC is unexplained at this time, but represent subtle differences in pan construction and gas sensor placement. The presence of forced air movement, however, is consistent with dilution of the cooking gases and thus a reduction in gas sensor output.

10.7 EFFECTS OF WATER, SOYBEAN OIL, AND AGING ON GAS SENSORS

10.7.1 Effect of Water

Two tests (73 and 74) were performed to determine how water vapor alone affected gas sensor response. The tests consisted of placing a 4-qt (3.78 L) pan 3/4 full of water, on the front burner on high heat setting for approximately 30 to 40 minutes. **Test** 73 was run with the lower hatch open to the kitchen allowing air to flow through the room. **Test** 74 was run with the lower hatch closed to the kitchen.

The data in Table 10.7.1A were used to calculate the change in voltage from 70 percent of the highest value (V2) to the highest value (V1). Seventy percent of the highest value was chosen to discriminate noise from signal in these tests.

Table 10.7.1A: The Voltage Change of the Gas Sensors at Site 7, 9, and 11

Test 73 -- 150 ml water boiled on a 8" stainless steel sauce pan on the right front burner of an electric open coil range; lower hatch of the test room was opened									
	Site 7			Site 9			Site 11		
Sensor Type	V1 volts	V2 volts	Δ volt	V1 volts	V2 volts	Δ volt	V1 volts	V2 volts	Δ volt
General Hydrocarbon	2.26	1.58	.68	2.12	1.48	.64	1.17	.83	.34
General Alcohol	1.52	1.06	.46	.81	.57	.24	1.31	.92	.39
Total Cooking	1.07	.75	.32	.82	.57	.25	1.03	.72	.31
Cooking Alcohol	*	*		*	*	—	*	*	—
Test 74 -- 150 ml water boiled on a 8" stainless steel sauce pan on the right front burner of an electric open coil range; lower hatch of the test room was closed									
Sensor Type	Site 7			Site 9			Site 11		
	V1 volts	V2 volts	Δ volt	V1 volts	V2 volts	Δ volt	V1 volts	V2 volts	Δ volt
General Hydrocarbon	2.23	1.56	.67	1.8	1.26	.54	*	*	—
General Alcohol	1.58	1.11	.47	.72	.5	.22	1.31	.92	.39
Total Cooking	*	*	—	*	*	—	1.05	.74	.31
Cooking Alcohol	*	*	—	2.35	1.65	.7	.82	.57	.25

* Eliminated because 70% of the highest value was below baseline.

If a sensor's signal had baseline voltages above the 70% value of thehighest voltage they were eliminated from the analysis. These sensors were cooking alcohol for sites 7, 9 and 11 for test 73. For test 74, total cooking and cooking alcohol sensors for sites 7 and 9, as well as general hydrocarbon and cooking alcohol sensor for site 11 were eliminated. Table 10.7.1A presents the remaining sensors and changes in voltage. The results showed that water vapor alone affected gas sensor responses to a small degree (less than 1V), but no differences were noted between the open hatch (Test 73) or closed hatch (Test 74).

10.7.2 Effect of Water and Soybean Oil

Tests were conducted using soybean oil and water to look at the effect of water on gas sensor response to soybean oil. The water and soybean oil test was conducted with 3 pots of water (2L in each pot) and 500 ml of soybean oil in a stainless steel pm on the right front burner of an open coil element electric range. To analyze the effects of water, the soybean oil and water test (test 47) was compared to a soybean oil test (test 45) at sites 7, 9, and 11.

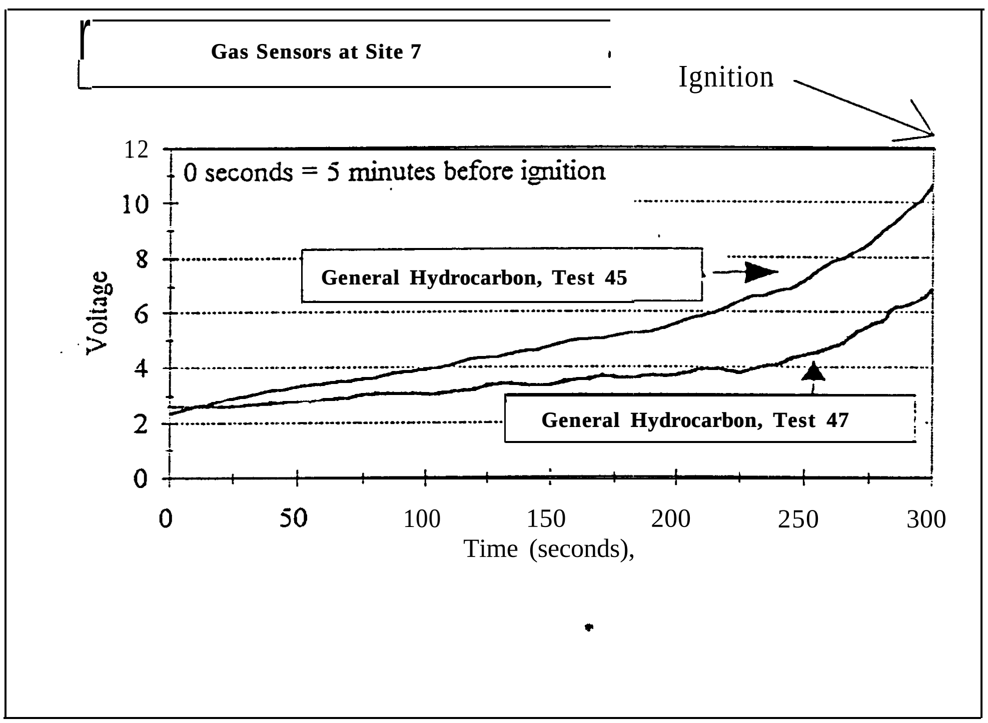

Figure 10.7.2A: General hydrocarbon sensor outputs at site 7 plotted against time for tests 45 (soybean oil) and 47 (soybean oil and water).

The 5 minute period before ignition was plotted for comparison to illustrate how water vapor affects the hydrocarbon sensor response. Figure 10.7.2A shows that test 47 signal output is consistently lower than the signal output for test 45 with the greatest difference (approximately 4V) occurring within 1 minute to ignition (at 80 seconds to ignition it is 2 V). Please note that Figures 10.7.2A, 10.7.3A, and 10.7.3B were smoothed using a 3 point (every 15 seconds) moving average ffor clarity.

Table 10.7.2A presents data for voltage changes over the same five minute period before ignition (time 0) and ignition (300 seconds). The water vapor clearly lowered the change in voltage responses for all sensors tested at all sites with the greatest effect noted on the cooking alcohol sensor where the AV decreased by over a half. While the water vapor alone caused a small positive response in gas sensors, the response of the gas sensors for the soybean oil test was suppressed when water vapor was present. This might be due to a dilution effect from water vapor or to oil particle enlargements through coalescence with water vapor.

Table 10.7.2A: Change in Voltage Over Time for Soybean Oil (Test 45) and Soybean Oil and Water (Test 47)

Test Number	Site Number		General Hydrocarbon	General Alcohol	Total Cooking	Cooking Alcohol
#45	Site 7	0 sec	2.32V	1.2V	DNF	1.82V
		300 sec	10.61V	6.61V	DNF	10.05V
		Δ Volts	8.29	5.41	---	8.23
#47	Site 7	0 sec	2.97V	1.62V	1.77V	3.34V
		300 sec	8.29V	4.37V	5.29V	8.61V
		Δ Volts	5.32	2.75	3.52	5.27
#45	Site 9	0 sec	1.05V	0.79V	0.84V	3.13V
		300 sec	6.45V	5.56V	4.94V	11.37V
		Δ Volts	5.4	4.77	4.1	8.24
#47	Site 9	0 sec	2.56V	1.66V	2.32V	8.66V
		300 sec	6.85V	5.19V	5.44V	11.4V
		Δ Volts	4.29	3.53	3.12	2.74
#45	Site 11	0 sec	0.85V	1.03V	0.59V	1.03V
		300 sec	3.46V	4.45V	2.61V	5.49V
		Δ Volts	2.61	3.42	2.02	4.46
#47	Site 11	0 sec	2.15V	1.8V	1.62V	2.12V
		300 sec	3.97V	4.04V	3.25V	4.75V
		Δ Volts	1.82	2.24	1.63	2.63

#45 - 500 ml of soybean oil in a 10 in (254 mm) diameter stainless steel frying pan. Frying pan was placed on the large rear burner. The pan was heated on high until ignition occurred.

#47 - 500 ml of soybean oil in a 10 in (254 mm) diameter stainless steel frying pan. Three 2.5 L of water in 3.8L (4 Qt.) stainless steel sauce pan. First heat oven to 204°C (399°F). Then heat water on high the three burners. Heat oil on high on the large rear burner for 5 minutes. Decrease heat under oil to medium-low. After oil reaches a steady state temperature, maintain for 15 minutes, and then increase heat to high until ignition occurs.

DNF - Gas sensor did not function

10.7.3 g of Sensors

To identify the effects of aging on gas sensors,. total cooking sensor 102 (new sensor) and total cooking sensor 103 (old sensor previously used by NIST) were evaluated for tests 7 (500 ml of oil heated on high to ignition using a stainless steel pan), 8 (duplicate of test 7), 43 (500 ml of oil heated on medium high using a stainless steel pan), and 44 (duplicate of test 43). Sensors 102 and 103 were located at site 10 (see Figure 8.2.1A, page 41). To evaluate these data, the output voltage was converted to an Rs/Ro ratio. This conversion was performed because the internal resistance varied within the same type of sensor, causing the sensor output to vary (and thus its response to a particular gas concentration). Therefore, to evaluate the sensors, the data were converted to a Rs/Ro ratio to overcome the variation in output voltage. The equations used for calculating the ratio were obtained from the gas sensor specification sheet.

$$Ratio = \frac{RS}{Ro}$$

$$R_s = \left(\frac{V_c}{V_{RI}} - 1\right) \cdot RI$$

The terms in the above equations are as follows: Ro is the average resistance calculated from the **first minute** of operation, R1 is 4.76 kΩ, Vc is the power supply voltage (equal to 15 V), V_{R1} is

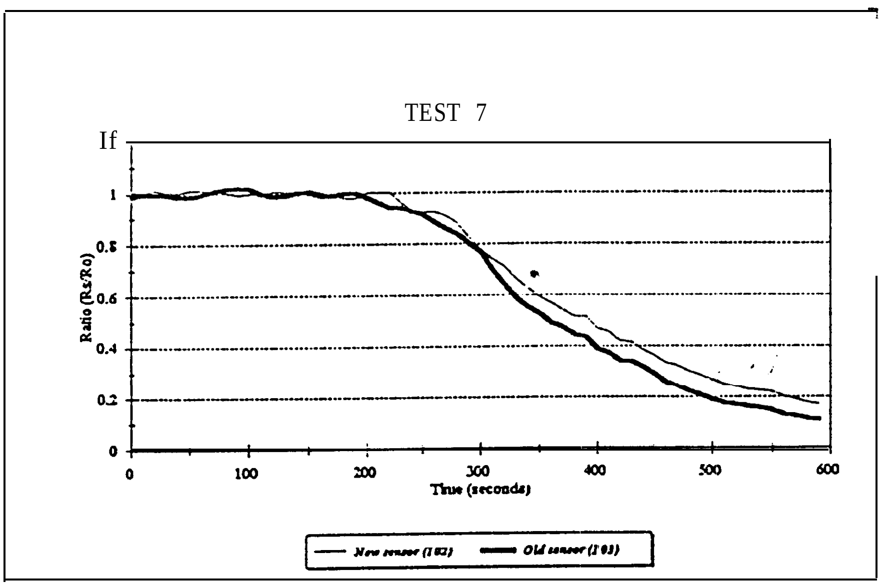

Figure 10.7.3A: Test 7; Test scenario -- 500 ml of soybean oil in a 10 in (254 mm) diameter stainless steel pan. Heated on high until ignition. Resistance ratio responses for total cooking sensors 102 and 103 plotted against time.

the varying output voltage, Rs is the resistance as a function of the varying output voltage V_{R1} calculated from the above equation, and the ratio is the resistance ratio used for plotting the sensor data. Rs/Ro is the ratio of the varying sensor resistance response to the baseline resistance response (average of the first minute of response). As can be seen from the Rs equation (and Figure 10.7.3A), the Rs/Ro decreases as the concentration of cooking vapors increase (higher output voltage $V_{R1} \rightarrow$ lower Rs resistance).

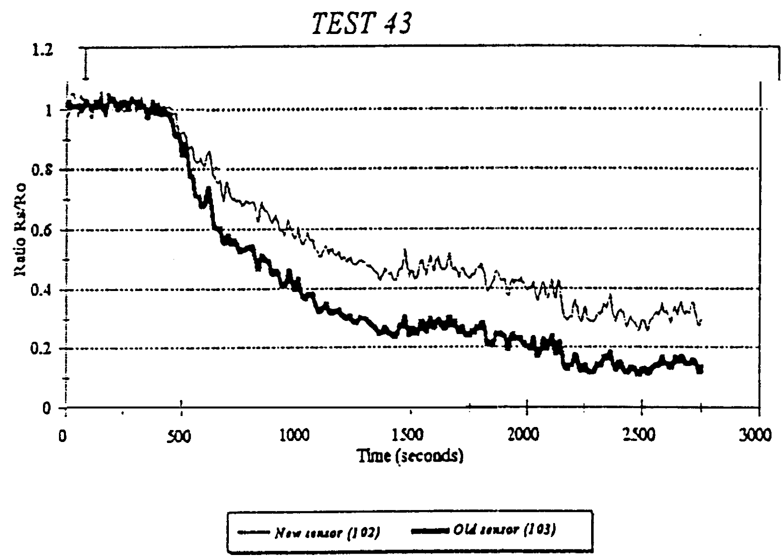

Figure 10.7.3B: Test 43; Test scenario -- 500 ml of soybean oil in a 10" (254 mm) diameter stainless steel pan. Heated on medium-high. Total cooking sensors' resistance ratio responses for sensors 102 and 103 plotted against time.

Analysis of sensor 102 and 103 data for tests 7 showed that the two sensors track each-other very well (see Figure 10.7.3A). Data for sensors 102 and 103 data from test 43 showed that the signals are also similar (see Figure 10.7.3B). In each case, however the old sensor (103) has a lower resistance ratio after the first few minutes of operation as the cooking vapors increased. Thus, the old sensor was similar in response to lower concentrations of cooking vapors, but became more sensitive as vapor concentration increased.

The resistance ratio drops for sensors 102 and 103 for tests 7, 8, 43, and 44 are listed in Table 10.7.3A. The table lists the ignition ratio value of Rs/Ro at ignition and value at one minute (Initial R_s/R_o). The two values were then subtracted from each other to produce the change in ratio over time value (A). The old sensor (103) ratio drop was again somewhat greater than that of the new sensor (102) perhaps indicating au increased sensitivity with aging.

Table 10.7.3A: Change in ratio over time for Test 7, 8, 43 and 44

	New Sensor (102)			Old Sensor(103)		
Test	Ignition Rs/Ro	Initial Rs/Ro	Δ	Ignition Rs/Ro	Initial Rs/Ro	Δ
#7	.153	.996	.843	.102	1.014	.912
#8	.183	.963	.78	.149	1.044	.894
#43	.308	1.073*	.765	.145	1.005*	.86
#44	.498	1.007*	.509	.335	.983*	.648

* End of test value because there was no ignition

10.7.4 Summary

The limited data. in this section indicated that water vapor alone causes a response in gas sensors with an increase in voltage above non-exposure voltage of 0.2 to 0.7 V. When oil was heated in the presence of water, however, responses were reduced to 40 to 80% of the signal obtained with oil alone in the 5 minutes before ignition. Gas sensor aging seemed to cause an increase in gas sensor responses as cooking oil vapor concentrations increased. The absolute effects of water on sensor response will be less at pan bottom temperatures of 340°C (644°F), but then sensor responses are also lower.

10.8 ADDITIONAL PRE-FIRE CONDITION DISCRIMINATION TESTS

This section describes additional cooking scenarios which supplement those of the NIST Phase II test plan. They represent both attended and unattended cooking tests that were added in response to recommendations made by AHAM. A total of eight tests were performed including caramelizing sugar (2 tests) on the electric range, deep frying chicken in soybean oil (2 tests on the open coil element electric range and 2 tests on the gas range), and cooking a fruit flarnbe (2 tests) on the electric range. The test scenarios were described in section 8.0. The following discussion is focused on the pan bottom thermocouple and the site 9 cooking alcohol gas sensor behaviors.

10.8.1 Deep Frying Chicken Tests on Electric and Gas Ranges

The pan bottom temperatures for the deep frying chicken in 2000 ml of oil on either a gas or electric range are shown in Figures 10.8A and 10.8B. The chicken tests on the gas range took twice as long to reach the auto-ignition temperature as on those on the electric range. The ignition temperatures were about 440°C (824°F) for the electric ranges and about 400°C (752°F) for the gas ranges which could be expected given the different cooking times.

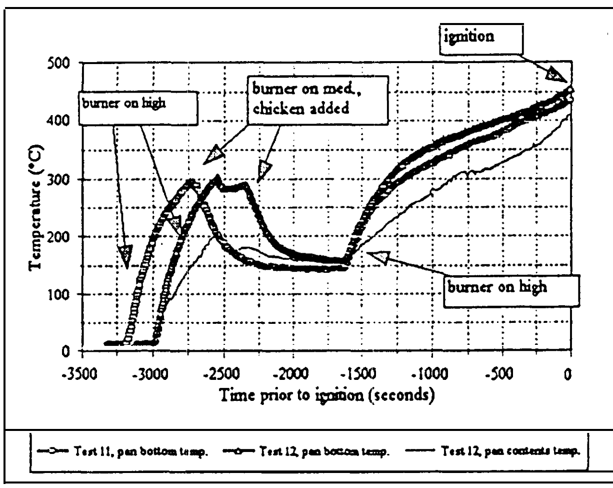

Figure 10.8A: Pan bottom and pan content temperatures plotted against time for deep frying chicken test scenario using an open element electric range

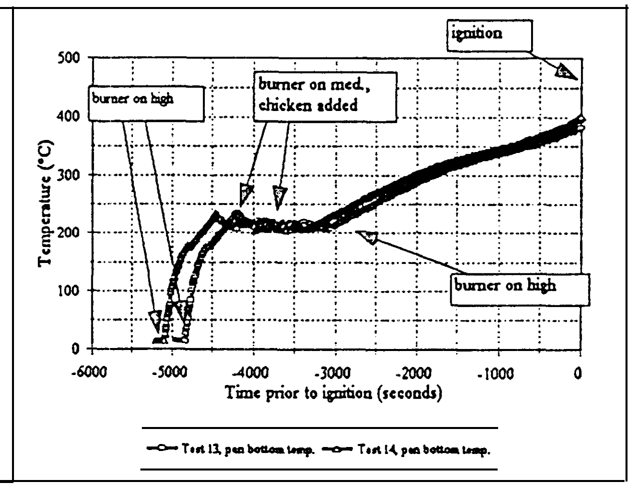

Figure 10.8B: Pan bottom temperatures plotted against time for deep frying chicken test scenario using a gas range

The cooking alcohol sensor responses for the two range types are illustrated by Figures 10.8C and 10.8D. As shown in Figure 10.8C for the electric range, the site 9 cooking alcohol sensor for test 11 exhibited a high baseline response which might have been caused by the cooking oil exposure from the previous test. The signal began to climb about 1000 seconds before ignition and about 500 seconds after being turned on. Figure 10.8D shows that with the gas range, the sensor responded as soon as the burner is turned on high (approximately 2800 seconds before ignition) and increased steadily to ignition.

The immediate response of the cooking alcohol sensor in the gas range may reflectthe release of gas combustion products and unburned gas into the test room. The response difference did not seem to relate to oil breakdown products since the rate of temperature rise is greater with the electric range.

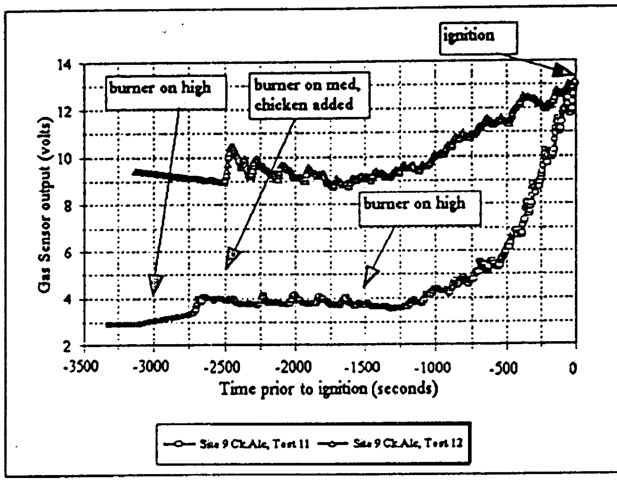

Figure 10.8C: Cooking alcohol sensor output plotted against time for deep frying chicken scenario using the electric range

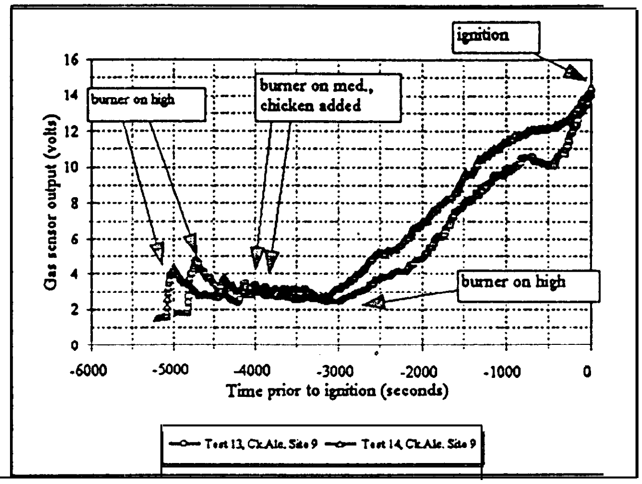

Figure 10.8D: Cooking alcohol sensor output plotted against time for deep frying chicken scenario using a gas range

108.2 Caramel Sugar Tests on the Electric Range

In the two caramelizing sugar tests (15 and 16), the results were repeatable as shown in Figures 10.8E and 10.8F. The pan bottom temperature curves in Figure 10.8E have similar trends and magnitude. Approximately two minutes after the burner element was set on high, both temperature curves ramped upward until they reached 250 to 260°C (482 to 500°F) and proceeded more gradually toward ignition at 330°C to 360°C (626 to 680 °F). Figure 10.8F presents the cooking alcohol sensor data at site 9 for caramelized sugar. Both test runs showed a similar trend, except that in test 16, the initial response was almost 2 V higher than the response of test 15. However, at ignition both sensor responses were around 13 V. It should be noted that after the burner was set on high, both test runs exhibited a similar peak, coinciding with the temperature plateau at 250°C (482°F). In test 16, it took 200 seconds for the alcohol sensor to peak, while test 15 took 100 seconds.

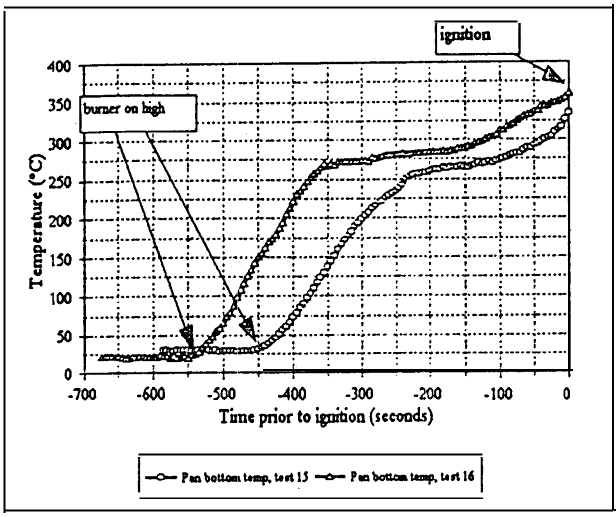

Figure 10.8E: Pan bottom temperatures plotted against time for the caramelized sugar test scenario

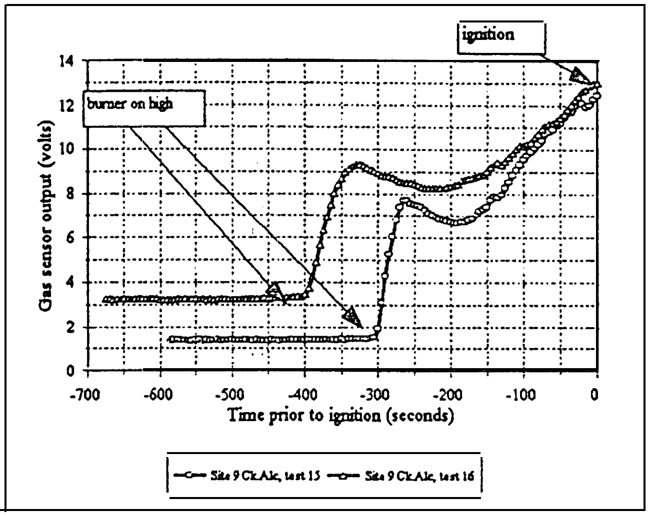

Figure 10.8F: Cooking alcohol sensor output plotted against time for the caramelized sugar test scenario

10.8.3 Banana Flambe Tests on the Electric Range

The results of an attended flambe cooking scenario are shown in Figures 10.8G and 10.8H. The pan contained brown sugar and butter before the bananas were added. In Figure 10.8G, when bananas were added, the pan content and pan bottom temperatures dropped as expected. The pan bottom temperatures had increased to around 200°C (392°F) by the time that the warmed brandy was ignited. Th.e typical flambe recipe calls for shutting off the burner prior to igniting the brandy. In this scenario, the burner was left on until the brandy was ignited to provide additional thermal energy to evaporate alcohol. As shown in Figure 10.8H, the alcohol sensor readings increased substantially after the brandy was added. The cooking alcohol sensor varied from an immediate change in voltage when the brandy was added (test 17) to a delayed response at approximately 90 seconds before ignition.

The results of these cooking scenarios indicated that gas sensors produced higher responses on gas ranges, while ignitions occurred at lower pan content and pan bottom temperatures.- They also indicated that caramelized sugar resulted in ignition at a pan bottom temperature of approximately 330°C to 360°C (626 to 680°F). This is lower than pan bottom temperatures at ignition observed for the other tests. The flambe tests involved ignition of added brandy, but not of the pan contents (the pan bottom temperature was low). This is, however, unlikely to be an unattended cooking scenario; it also has a much lower fuel load than a test involving 500 ml of oil.

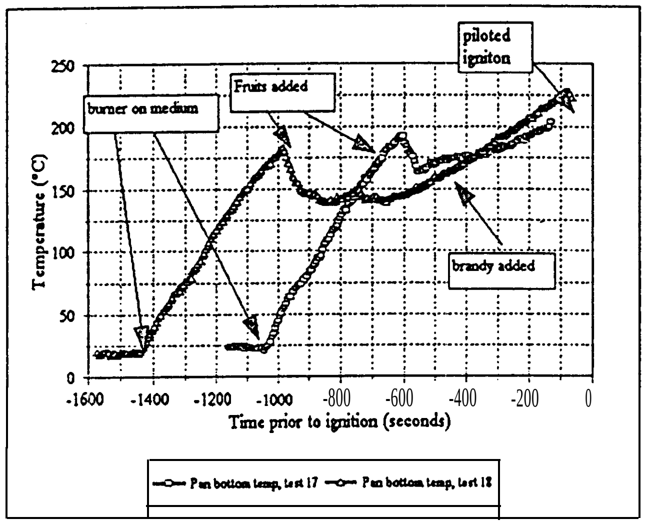

Figure 10.8G: Pan bottom temperatures plotted against time for flambe test scenario

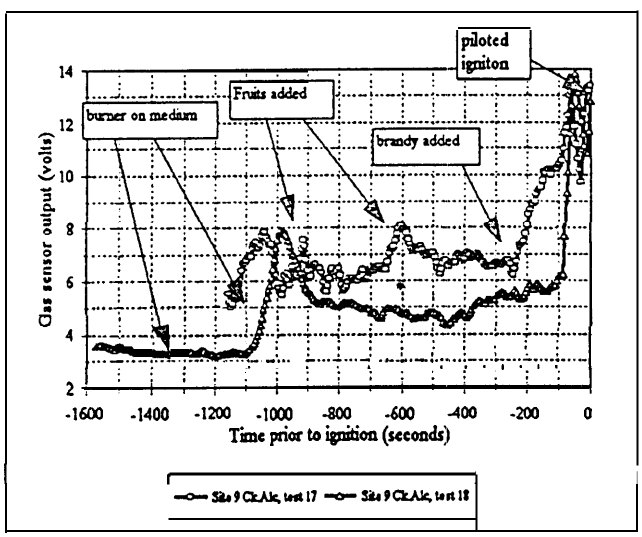

Figure 10.8H: Cooking alcohol sensor output plotted against time for flambe test scenario

10.9 SMOKE DETECTOR PERFORMANCE

10.9.1. Introduction

Most of the smoke detectors investigated in this section of the range fire report were photoelectric detectors. Due to battery failures, only one ionization detector produced usable data.. Detector responses were examined under varying combinations of cooking systems (ranges and pans), food type and quantity, and induced air currents.

A total of 62 relevant tests conducted by the CPSC under the test plan (Tables 3 through 6) were examined at a pan bottom temperature of 360°C (680°F) because this temperature was originally thought to account for the thermal inertial effects of the cooking system. Subsequent analysis indicated that 340°C (644°F) is the actual pan bottom temperature of concern (sections 10.3 and 10.4). Rather than reanalyzing the smoke detector data, it was decided to present the 360°C (680°F) data, recognizing that response rates would only be lower at 340°C (644°F).

10.9.2 Anomalies in the Performance of Smoke Detectors During the CPSC Test Program

Several problems were encountered in the evaluation of smoke detector performance. First of all, when the "control panel" type of photoelectric smoke detector entered alarm mode, it had to be "reset" by interrupting its power supply after smoke had cleared from the area. Both NIST and CPSC experienced instances in which these detectors did not reset between tests.

Additionally, all of the "single station" ionization detectors were powered by disposable batteries. New batteries of the appropriate type were installed in each detector at the beginning of the CPSC test: program. Batteries were changed in several of the battery powered detectors in response to "low battery" signals during the CPSC test program. Review of the data developed from the battery powered ionization detectors indicated that the detectors began to perform erratically shortly after initiation of the CPSC test program. NIST also experienced such erratic performance with these same detectors. The detectors were evaluated by monitoring selected voltages after installation of fresh batteries suggested by the manufacturer of the detectors. Those voltages indicated that the detectors were capable of proper operation. The ionization detectors were returned to the manufacturer for additional analysis which confirmed that the batteries used during the CPSC test program were defective.

The following discussion excludes instances during which a photoelectric smoke detector did not reset or when the data suggested that a failing battery had disabled an ionization smoke detector.

10.9.3 False Alarms

For the purposes of this analysis, a smoke detector alarm during the attended cooking portion of a test, or an alarm during a test which does not end in ignition, is considered to be a "false alarm." The CPSC test plan included scenarios that began as attended cooking activities and continued as unattended cooking because they were thought likely to' result in ignition. ' There were five such scenarios involving duplicates using both gas and electric ranges for a total of 14 such tests. In addition, one scenario (test numbers 17 and 18) involved intentional ignition of the food at the end of an attended cooking sequence ("Flambe"). The smoke detectors were able to respond to all of these scenarios but, in some cases as indicated in Table 10.9.3A, alarmed prior to completion of the attended cooking portion of the test. The percentage of detectors that alarmed prior to completing the attended cooking ranged from 23 to 50% when flambe tests are included and 9 to 30 % when flambe tests are excluded. The highest percentage of false alarms in each case occurred with the photoelectric detectors at sites 9 and 11 and ionization detectors at site 14.

Table 10.9.3A: Smoke Detector False Alarms During Attended Cooking

	FALSE ALARMS Alarms During Attended Cooking Portions of Test Scenarios				
	Photo # 5	**Photo # 9**	**Photo # 11**	**Photo # 14**	**Ion # 14**
Includes Flambe	4	7	6	3	3
Alarm During Attended Cooking (%)	30.7	50	46.2	23.1	50
Opportunities to Alarm	13	14	13	13	6
Excludes Flambe	2	5	4	1	3
Alarm During Attended Cooking (%)	18.2	41.7	31.4	9.1	50
Opportunities to Alarm	11	12	11	11	6

*** Opportunities To Alarm -- is the number of tests during which the smoke detector of the type and at the location indicated was functional**

A total of 23 tests conducted under the CPSC test plan ended without ignition. The smoke detectors alarmed during most of those tests. Table 10.9.3B indicates the numbers of instances of both false alarms and no alarms for tests which ended without ignition. The percentage of alarms without ignition ranged from 81 to 100%.

Table 10.9.3B. Smoke Detector False Alarms During Tests Ending Without Ignition

		False Alarms During Tests Ending Without Ignition				
		Photo # 5	**Photo # 9**	**Photo #11**	**Photo # 14**	**Ion # 14**
No Alarm	**Number**	**4**	**4**	**2**	**4**	**0**
	%	19.1	18.2	9.5	19.1	0
Alarm Prior to Completion Of Test	**Number**	**17**	18	19	17	**3**
	%	81	81.8	90.5	81	100
Opportunities	**Number**	21	22	21	21	3

***Opportunities To Alarm – is the number of tests during which the smoke detector of the type and at the location indicated was functional**

10.9.4 Failure to Alarm Prior to Ignition

All of the monitored smoke detectors alarmed in each test -which ended in ignition. Table 10.9.4A indicates that the number of tests which ended in ignition, the number of those tests during which each of the smoke detectors was functional, and the responses of those detectors relative to ignition. However, only the photoelectric detector at location 5 was 100% successful at alarming prior to ignition. Detectors at the other locations were successful at alarming prior to ignition during approximately 85 to 93% of such tests. Except in the single case of photoelectric detector #14 during test number 19, all of the photoelectric detectors which failed to alarm prior to ignition did so only when the operation of the range hood and ceiling fan substantially disrupted the plume rising from the heated food. The combination of heating the pan and its contents on a rear burner with the range hood fan operating at its maximum flow rate had the most impact on the performance of the smoke detectors. Ten of the eleven instances in which photoelectric detectors failed to alarm until after ignition during this series of tests involved the combination of rear burner/range hood fan on. The eleventh instance of a photoelectric detector failing to alarm until after ignition also involved operation of the range hood or ceiling fan. The ionization detector was functional for too few of these tests to permit conclusions.

Table 10.9.4A: Smoke Detector Responses During Tests Ending in Ignition

SMOKE DETECTOR RESPONSES DURING TESTS ENDING IN IGNITION						
		Smoke Detector Identification				
		Photo #5	Photo # 9	Photo #11	Photo #14	Ion #14
No Alarm	Number'	0	0	0	0	0
	%[b]	0	0	0	0	0
Alarm After Ignition	Number[a]	0	3	4	5	3
	%[b]	0	6.7	8.5	10.9	15
Alarm Prior to Ignition	Number'	47	42	43	42	17
	%[b]	100	933	91.5	89.4	85
Opportunities To Alarm [c]	Number	47	45	47	47	20

Numbers the number of instances in which the Smoke Detector of the type and at the location indicated met the specified criteria.
% is the "Number" divided by the "Opportunities To Alarm" x 100.
Opportunities To Alarm is the number of tests during which the Smoke Detector of the type and at the location indicated was functional

10.9.5 Time to Alarm Compared to Minimum Time Required for Successful Intervention

Table 10.9.5A indicates the number of tests which ended in ignition and the responses of each smoke detector relative to the time at which the pan bottom reached 360°C (680°F). Photoelectric detector # 5 had alarmed in every test prior to ignition but had failed to alarm at 360°C (680°F) or less in 58% of the tests. Photoelectric detector #9 had alarmed prior to ignition in approximately 93 % of the tests but alarmed at 360°C (680°F) or less in approximately 60% of the tests. The other detectors had even lower success rates both in terms of alarming prior to ignition and in alarming at 360°C (680°F) or less. Table 10.9.5A also presents data on the percentage of detectors alarming at 2 and 4 minutes before ignition. Due to thermal inertia effects, alarrning at two minutes or less can be too close to ignition for successful intervention while those between two and four minutes are less likely to progress to ignition.

Table 10.9.5A: Smoke Detector Responses **Relative** to Pan Bottom Temperature

SMOKE DETECTOR RESPONSES RELATIVE TO PAN BOTTOM TEMPERATURE						
		Smoke Detector Identification				
		Photo #5	**Photo #9**	**Photo #11**	**Photo #14**	**Ion #14**
Alarm At Or Before Pan Bottom Temperature = 360°C	**Number**	**23**	**23**	**22**	**16**	**7**
	%	**57.5**	**60.5**	**55**	**40**	**35**
Alarm After Pan Bottom Temperature = 360°C	**Number**	**17**	**15**	**18**	**24**	**13**
	%	**42.5**	**39.5**	**45**	**60**	**65**
Alarm Within Two Minutes of **Ignition**	**Number**	**9**	**8**	**4**	**15**	**9**
	%	**19.2**	**17.8**	**8.5**	**31.9**	**45**
Alarm Within Four Minutes of Ignition	**Number**	**30**	**21**	**26**	**29**	**12**
	%	**63.8**	**46.7**	**553**	**61.7**	**60**
Opportunities to Alarm	**Number**	**40**	**38**	**40**	**40**	**20**
Opportunities To Alarm is the number of tests during which the Smoke Detector of the type and at the location indicated was functional						

the detector relative to the pan contents and the operation of the range hood or ceiling fan. Only the photoelectric detector at location 5 was 100% successful at alarming prior to ignition. These detectors also alarmed during the attended cooking portion ("false alarmed") in 23 to 50% of those tests and also "false alarmed" in 81 to 90.5% of the tests which did not end in ignition.

When, however, thermal inertia is considered, photoelectric detectors alarmed prior to the temperature of the pan bottoms reaching 360°C (680°F) in only approximately 40 to 60% of the tests where such a comparison could be made. Results at 340°C (644°F) would be even less favorable.

Air flow using a ceiling fan or range hood was the primary cause of detectors to alarm before. ignition. A photoelectric detector with appropriate (perhaps, non-standard) calibration in the forward edge of the range hood might offer the best possibility of striking the balance between premature or false alarms which could disrupt attended cooking while also providing an alarm early enough to avoid ignition due to thermal inertia. The effects of air flow and pan position must be considered for whatever detector is used.

11.0 POSSIBLE CONTROL SYSTEM APPROACHES

This section presents a discussion of possible pre-fire control system approaches for cooking ranges. The test'results presented in previous sections showed a range of temperature, gas sensor and other detector signals which occurred during cooking. These tests have identified signals associated with conditions leading to ignition. Analysis of these signals can identify pre-ignition conditions that could be used to reduce the risk of cooking fires and still allow attended. cooking. Prior to discussing examples of possible control systems, the major findings of this study on detector function will be summarized and possible requirements for a control system presented.

11.1 MAJOR FINDINGS FROM TEST RESULTS ON DETECTION DEVICE FUNCTION

This section summarizes the major findings from the different test phases on detector function and how these might be used in possible control systems. The laboratory test results indicated that the three major types of detectors - thermocouples, smoke/fire detectors, and gas sensors - all may have some potential for use in a control system. The results also indicated that further testing and development would be needed before the gas sensors and smoke detectors could be used in a control system.

Pan bottom thermocouple(s) provided consistent pre-ignition responses for metal pans and could provide adequate responses for ceramic pans if they are correctly positioned.

The photoelectric smoke detectors used in these tests alarmed before ignition in most instances. However, as presently designed these detectors also alarmed during attended cooking and failed to alarm adequately when air flow was a factor. The ionization smoke detector data were very limited due to operational problems during testing. The data collected, however, were similar to those for photoelectric detectors. Therefore, greater ability to discriminate would have to be developed before either of these devices could provide reliable, optimum responses.

The tin oxide gas sensors that exhibited discriminant pre-ignition signals in the absence of forced air flow conditions were the general hydrocarbon, general alcohol, total cooking gasses, and cooking alcohol sensors. The responses of all of these sensors were substantially reduced by air flow . Gas sensors also tended to produce significant signals during attended cooking and had fluctuating baseline voltages. Additionally, gas ranges appear to affect gas sensor responses as does water vapor and exposure to cooking oil vapors.

While the pan bottom thermocouple was the strongest candidate for a potential control system, other gas sensor types and smoke/fire detectors might also be modified to improve their capabilities in detecting pre-fire conditions.

Besides selecting the most reliable sensors, there are other factors that need to be considered in evaluating a potential control system. These include the effects of thermal inertia, pan material variability, pan position, burner size, type of range, type of fan, and air flow. Test results indicate that thermal inertia effects can be considerable in electric ranges. Depending on the shut off temperature, pan content temperatures can increase by as much as 60°C (108°F) and up to 120 seconds after the stove is turned off. The results also showed that differences in the thermal conductivity of ceramic cooking vessels can cause the temperature to vary over the pan bottom. These differences indicated the need for multiple pan bottom thermocouples to adequately define temperature. Any control system would need to factor these considerations into the design.

Staff in the Food Appliances section at Good Housekeeping indicated that 288°C (550°F) is the maximum temperature necessary for most cooking. Further, it is also the maximum food temperature for safe cooking cited in Underwriter's Laboratories Standard 1083 governing the operation of electric frying pans. The consideration of thermal inertia also supports a pan content temperature of about 300°C (572°F) (pan bottom temperature of 330°C [626°F]) if the risk of fire is to be minimized. Special high temperature cooking needs could be dealt with by including an override feature as part of a control system.

Based on the data developed in this study, a pan bottom temperature of 340°C (644°F) was chosen as an activation point. This temperature allowed food to be cooked to around 290 to 300°C (554 to 572°F). From the probability curve in Figure 11.2A under conditions experienced in the CPSC testing, the fire probability of ignition is less than 0.025 at a pan bottom temperature of 340°C (644°F). If a higher probability of ignition is acceptable, a higher critical temperature could be chosen.

The inclusion/exclusion of the sugar tests depends on whether they are classified as attended or unattended cooking. The caramelizing of sugar would usually be considered as being attended, since the process requires nearly constant stirring. However, from a fire point of view the process could be left unattended.

11.2 POSSIBLE SYSTEM REQUIREMENTS FOR A RANGE FIRE PREVENTION SYSTEM

Before control systems can be developed and evaluated for effectiveness and reliability, specific requirements for such a system need to be defined. First, a range fire prevention system should not require user action, but should allow a high degree of user flexibility in their cooking activities. That is, the system should allow for attended cooking to proceed normally while protecting against the development of a fire condition which could result in property damage, injury or death in the event of unattended cooking.

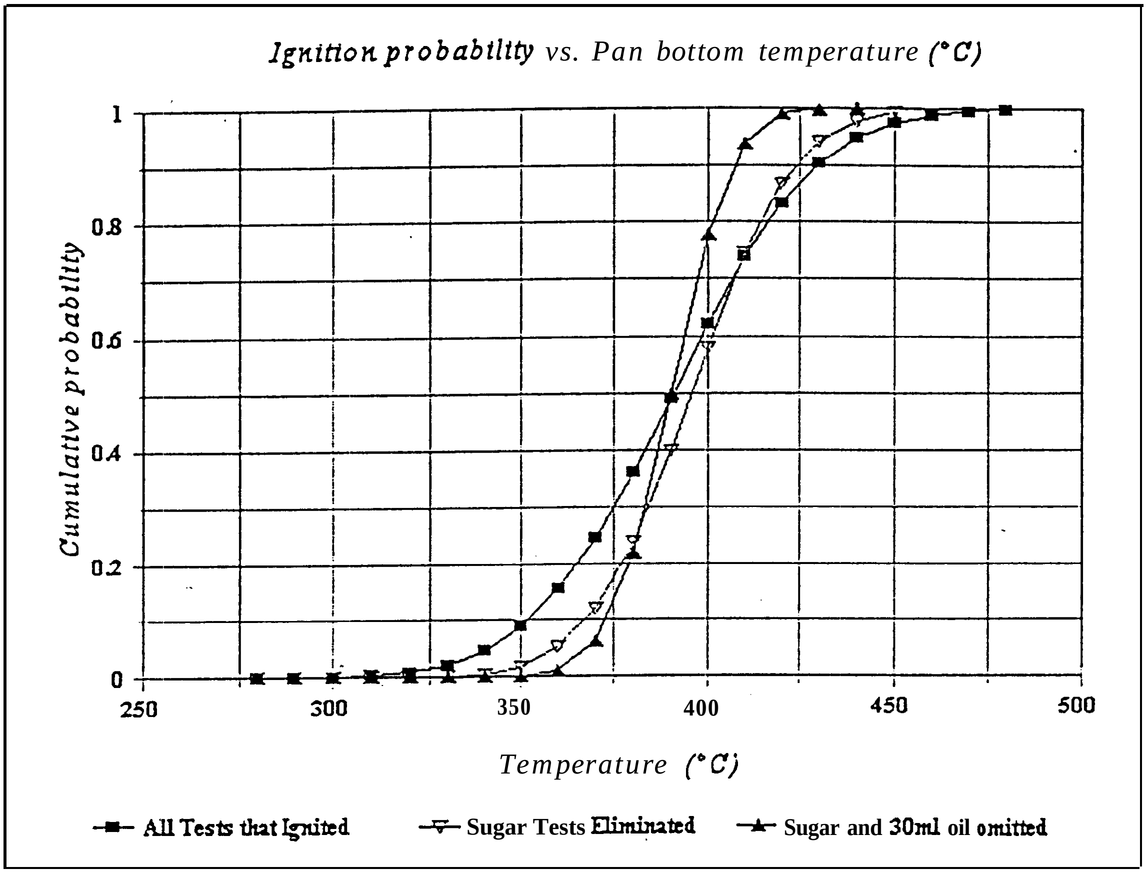

Figure 11.2A: Ignition probability based on CPSC tests

The purpose of a control system would be to detect situations for which an ignition condition is likely if the existing conditions are not modified by modulating the heat input from the range to minimize the likelihood of fire (i.e., the system may not prevent all fires).

11.3 POSSIBLE SYSTEM APPROACHES

This section discusses three possible approaches for pre-fire detection systems for range fires. The objective is to develop control approaches using inputs from thermocouples and/or gas sensors which may reliably "cycle" the heat input and prevent ignition The particular control scheme would depend on what criteria are selected to indicate a pre-ignition area Cycling is clearly the preferable mode of operation if a goal is to minimize the cooking disturbances.

Three types of control system approaches were developed:

a. a simple thermostat using the pan bottom temperature,

b. a system using pan bottom temperature and its time rate of change, and

c. a combination of pan bottom temperature and a general alcohol sensor signal at a specific location.

11.3.1 First Approach -- A Simple Thermostat.

This approach entails sensing the temperature at the pan bottom and shutting off or cycling the range when'a predetermined temperature is reached. A pan bottom temperature of 340°C (644°F) was selected so that a pan content temperature would be about 290°C (554°F) and the possibility of ignition would be low.

For the purposes of this discussion the "thermostat" may be run in one of two modes: a cycling thermostat or a one-shot (manually resettable). A cycling thermostat should be set to a "safe", lower temperature where prolonged operation does not lead to fire, as opposed to a one-shot. If the stove equipped with a cycling thermostat is left unattended, the pan interior may eventually "cycle up" to a higher than desirable temperature. Ignition might then occur unless there is a temperature to shut off the range. On the other hand, if there is only a one-shot trip, the stove shuts off and stays off. A trip temperature for a one-shot must be carefully chosen so as not to allow ignition, and still avoid nuisance tripping (which is more obvious to the user with a one-shot than with a. cycling thermostat). It may be possible to have a shut off feature combined with a cycling approach. Figure 11.2A shows that with a trip pan bottom temperature of 340°C (644°F), 97% of the potential ignitions would be detected when all of the pan contents tested were considered.

11.3.2 2nd Approach -- Sensing Temperature and its Differential

This approach is intended to limit nuisance shut offs during attended cooking when there is a chance that the pan bottom temperature may reach 340°C (644°F) before it is necessary to shut off or cycle the stove. This is more likely to occur at high rates of heating. The thermostat approach described above works best as the system approaches steady state (where the pan bottom and pan content temperatures are very close and not changing at a high rate). It is however, susceptible to nuisance shut off (especially if a one shot trip mechanism is used) in situations involving high initial rates of heat where the pan content temperature can lag the pan bottom temperature by a large amount.

The temperature and its time derivative approach uses the rate of change of temperature with time (dT/dt) to lessen the likelihood of ignition. A lower temperature would be chosen for cycling as the temperature approaches steady state. A higher temperature may be more appropriate in the initial heating situations because the pan bottom temperature can be substantially higher than the pan content temperature and ignition may be unlikely.

Figure 11.3A shows a plot of pan bottom temperature versus the time derivative of pan bottom temperature with respect to time. Data from various test runs (oil, chicken, bacon, soybean oil with water) are superimposed and used to separate the data into three regions - alarm, cycling, and non-ignition. For purposes of illustration, a criterion of 120 seconds before ignition was selected to separate these conditions and account for thermal inertia considerations. This is not the only criterion, however, it is used here for purposes of illustration to establish potential control system boundaries.

Note that for the majority of the data points, non-ignition or within 120 seconds of ignition are between -0.5 and 2.0°C/sec (-30 and 120°C/min). At the low temperatures (start of test runs), a large cluster of data points are at rates between -0.5 to 0.5°C/sec. This represents fluctuations that the pan bottom thermocouple experiences when the electric burner is initially activated. Higher rates of heat rise (1 to 2°C/sec) are achieved when the pan bottom temperature is in the 50 to 150°C range. When the pan bottom temperature is above approximately 150°C, the non-ignition data points spread out to -0.5 to 2°C/sec. The negative dT/dt's in the 150 to 200°C pan bottom temperature range represent food test scenarios where cold chicken is placed in the pan at this temperature range. The data points eventually return to the -0.5 to 0.5°C/sec region at pan bottom temperatures near ignition because the difference between the pan content-and pan bottom temperatures becomes small as ignition approaches.

Based on this characteristic behavior, at any time during the cooking process, pan bottom. temperature (T) and the derivative of temperature (dT/dt) can be measured and the resulting point (dT/dt, T) can be compared to the plot of Figure 11.3A. If the resulting point lies on the alarm side of the curve, the range is turned off. Otherwise, the range would remain on. This model may be run in a cycling mode by continuously measuring T and dT/dt in real time and cycling the range when the point (dT/dt, T) lies in the cycling region and turning the range back on when it reaches the non-ignition region. By recognizing some basic combinations of T and dT/dt, it is possible to determine the conditions of the cooking vessel at any time during a cooking session. For example, a pan bottom temperature of 300°C (572°F) or lower and low dT/dt indicates non-ignition conditions. High dT/dt and medium T (50 to 200°C [122 to 392°F]) indicate rapid heat rise rate (non-ignition conditions). High T and low dT/dt indicate near ignition conditions. More sophisticated algorithms for control systems that envelope the ignition data points could be used to model the ignition data more closely.

In constructing a prototype, the effects, if any, of using a cycling mode need to be factored into the control boundaries. To further develop this model, data on pan behavior when the range is turned on or cycled would be necessary to find the “best” curve, since the cycling limits may be slightly lower than those for the one shot method. Further data analysis for temperature cycling needs to be done to assess the effectiveness of cycling.

As can be seen in Figure 11.3A, some ignitions are possible in the cycling range. These are associated with the caramelized sugar test scenarios.

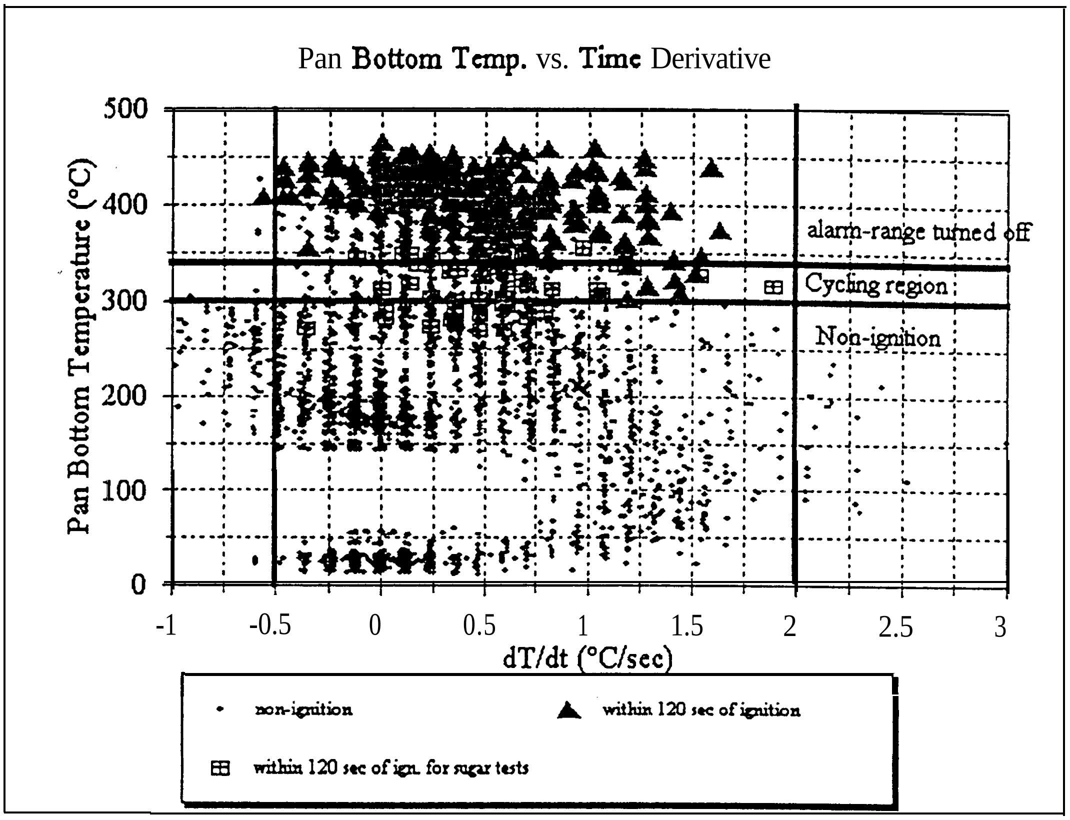

Figure 11.3A: Pan bottom temperature versus time derivative of pan bottom temperature for various test scenarios

11.3.3. Third Approach: Combination of Signals From the Pan Bottom and General Alcohol Sensor

This approach was examined to address an outcome of the work performed by NIST which suggested that a combination of pan bottom temperature and the general alcohol sensor at site 9 may be better than either sensor alone. The purpose of this type of combination would be to increase the sensitivity of the control system to pan contents such as caramelized sugar that can ignite at temperatures lower than cooking oils.

Figure 11.3B shows a combined plot of pan bottom temperature versus sensor voltage including chicken, oil, oil+water, bacon, and sugar. Based on Figure 11.3B, two line segments were drawn (one at a pan bottom temperature of 400°C (752°F), the other a diagonal) as a decision "curve" to determine whether or not the system should be in an alarm or non-alarm state. At lower sensor voltages, higher pan bottom temperatures are allowed.

In an application of the data in Figure 11.3B, the chicken would trip around 380-390°C (716 to 734°F), the oils around 350-370°C (662 to 698°F), the bacon around 330-340°C (626 to 644°F), and the sugars around 260-300°C (500 to 572°F).

A gas sensor by itself will not be a viable control approach since there is no good vertical line in

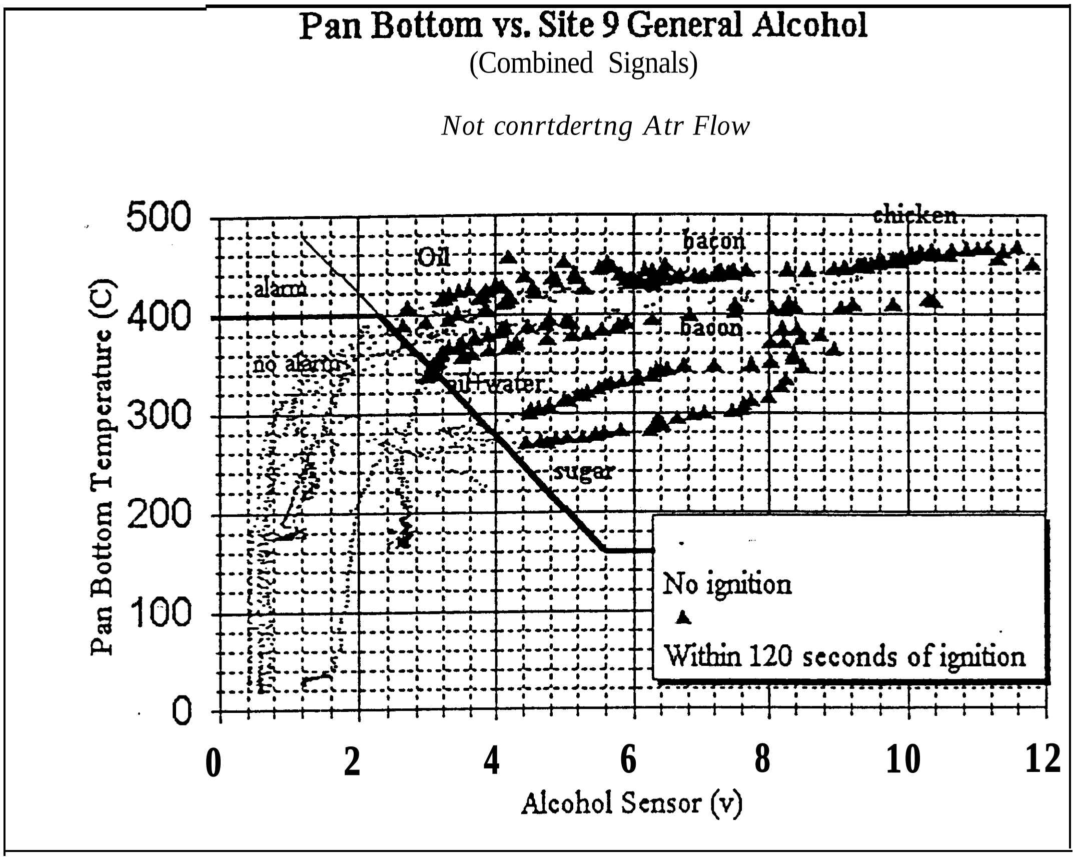

Figure 11.3B: Plot of combined foods.

Figure 11.3B to separate the triangles (within 120 seconds of ignition) from the dots (non-ignition). A few data points within 120 seconds of ignition still occurs before the diagonal line. These are associated with oil and water test scenarios.

Data obtained from tests using 500 ml of oil, however, clearly demonstrate that airflow affects the reading of the general alcohol sensor (Figure 11.3C). This figure overlays the oil tests with airflow (data points with boxed "x") on Figure 11.3B (tests with no forced airflow). The plot shows that airflow caused a substantial decrease in the general alcohol sensor signal for the 500 ml of oil scenarios (the only one involving air flow tests). Thus, rather than signals in the 3 to 6 volt range, the signal range decreased to 0.8 to 3.8 volts (with most of the, data points being less than 2 volts). Since it would be expected that airflow with other cooking scenarios (bacon, chicken, and sugar) would also cause a reduction in sensor signals, the trip temperature line under air flow conditions would clearly need to change. The other differences in gas sensor function for gas versus electric ranges also need to be considered as do other aspects of sensor function discussed in section 11.4 if gas sensors are to be used as a component of a range fire prevention system.

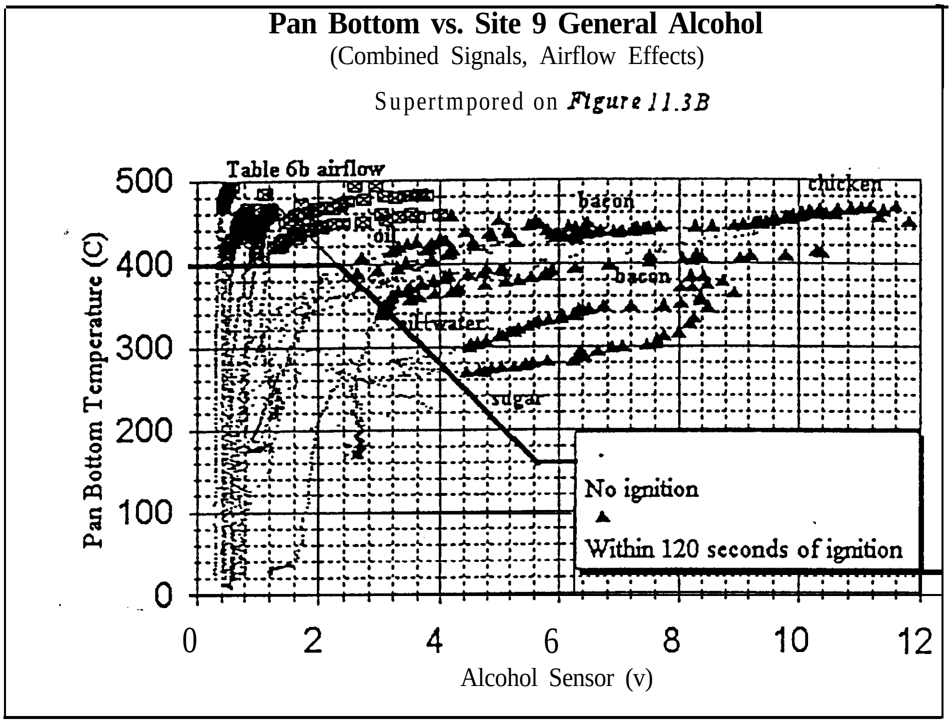

Figure 11.3C: Inclusion of Airflow Test Data

11.4. ADDITIONAL RESEARCH

The results of the CPSC and NIST testing identified issues involving the performance of gas sensors and fire/smoke detectors. These included chemical and physical interferences, drift, changes in baseline sensitivity and recovery times for cycling. Although some of these, such as drift, may be dealt with by using rate of change of the detector signal, implementation of such approaches increases the complexity and reliability, and may increase the cost of control systems. The staff recognizes that further development of gas sensor technology may yield better discrimination between the gases produced and the gases they are intended to detect, and may minimize the effects of air flow. More effective gas sensors and refinement of sensor location(s) could make the combination of temperature and gas sensors a more sophisticated control system. Contaminant build up on gas sensors may be an issue that needs to be addressed in future development.

Each of the control system approaches described in this section shows some potential as **a range** fire control system. The limitations of the current generation of gas sensors and smoke detectors, their relatively high costs, and system complexities suggest that a thermocouple based system may be preferable. Future efforts should involve building **a** prototype and testing the model for various cooking scenarios and for a long term reliability.

12.0 CONCLUSIONS AND RECOMMENDATIONS

12.1 CONCLUSIONS

The following conclusions are based on measurements and observations obtained with the detection devices, ranges, pans, pan contents, and the model kitchen used in this study. Extrapolations to other conditions should be made with these limitations in mind. Although some sensors might not have responded adequately or consistently in this study, it may be possible to modify them with additional development to function adequately.

- Comparison of testing performed at NIST and CPSC showed reproducible pan bottom and pan content temperatures as the tests approached ignition. In analogous tests conducted by the two laboratories, signals from gas sensors showed similar patterns during the 6 minute period before ignition.

- Both CPSC and NIST data confirmed that as cooking proceeds from attended to unattended conditions, changes occurred in the model kitchen environment. The primary changes were increases in the temperatures of the cooking vessel and its contents, the concentrations of gases or fumes associated with the cooking process, and particulate material in the form of smoke or grease particles produced during cooking.

- Pan bottom thermocouples provided the most consistent and reliable method for detecting pre-fire conditions.

- Tests with soybean oil (500 ml), where ignition occurred, had pan bottom temperatures ranging from 386 °C to 494°C and pan content temperatures ranging from 365 °C to 4 19 °C at ignition. The 30 ml tests had widely varying pan content temperatures at ignition (345 °C to 459°C). This variation was believed to be due to incomplete immersion of the pan content thermocouple in such a small volume of oil.

- Thermal inertia caused temperature increases of 16 to 50°C (29 to 90°F) in the pan contents after an electric range was shut off. The increase was affected by the amount of oil and the temperature at shut off. Based on this, pan bottom temperatures around 340°C (644°F) would be necessary to minimize the likelihood of ignition.

- Ceramic pans do not conduct heat as well as metal pans. Thermocouple position was important for obtaining an accurate temperature reading for the ceramic pan bottom. There is a need for at least two thermocouples.

- Gas sensors provide a measurable signal change as cooking proceeds from attended cooking to the point where ignition occurs. The location of the gas sensors and smoke detectors affected the magnitude of the signals they produce. As the device was placed closer to the source of fumes and the resulting plume, the signal strength increased.

Signals, however, were generally low until contents approach ignition, and were partially depressed by the presence of water vapors. The type of range, pan position, volume of oil, and heat setting can affect the generation of gases and hence sensor response. Sensors can also become contaminated.

- Disturbing the air in the vicinity of the gas sensors with ceiling fans or range hoods reduced the gas sensor signals to 5 to 10 percent of the signal obtained when no air movement occurred.

- Smoke detectors, as tested in the CPSC study, failed to alarm before ignition occurred in 0 to 15% of the tests (depending on location) but alarmed within 2 minutes of ignition (which may be too late to prevent ignition) 18 to 45 percent of the time. In tests where no ignition occurred, smoke detectors, depending on type and location, alarmed in 81 to 100 percent of the tests. They were also negatively affected by air flow.

12.2 RECOMMENDATIONS

Based on the above conclusions, the following recommendations are proposed:

- Meet with manufacturers of gas sensors and smoke detectors to discuss modifications to existing sensors/detectors that could allow their use in pre-ignition control system for ranges. This would include overcoming problems with alarming during normal cooking, interfering substances, contamination, and air flow.

- Develop a prototype control system to test for long term reliability in preventing range fires using thermocouples alone or in combination with gas sensors or smoke detectors (if they can be sufficiently improved). Such tests should be conducted under a variety of cooking and environmental conditions.

13.0 REFERENCES

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